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EFFECTS OF SYNTHETIC DETERGENTS
ON OPERATION OF A SECONDARY
SEWAGE TREATMENT PLANT

A THESIS

Presented to
The Faculty of the Graduate Division

by

John Alexander Little

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of the Requirements for the Degree
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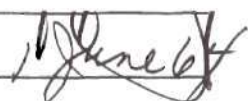
May, 1963

EFFECTS OF SYNTHETIC DETERGENTS
ON OPERATION OF A SECONDARY
SEWAGE TREATMENT PLANT

Approved:



Date approved by Chairman:



FOREWORD

Most researchers believe that synthetic detergents (syndets) affect many of the sewage treatment processes. It is the primary intent of this study to investigate the effect, if any, of syndets on operation of the Dalton, Georgia, sewage treatment plant. The standard quality characteristics of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were utilized extensively in the investigation.

The assistance of Mr. V. D. Parrott, Jr., Superintendent, Utilities Commission, Dalton, Georgia, and of his staff is hereby gratefully acknowledged. Because of their valuable help and with their permission, this research project was made possible.

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SUMMARY

Following World War II, the sale of synthetic detergents on the American market began to grow at a phenomenal rate. Traces of spent detergents quickly found their way into sewer systems throughout the country. Then, in 1947, the first reported complaint that synthetic detergents were interfering with sewage treatment processes was sounded at Mt. Penn, Pennsylvania. Since that time, the alleged detrimental effects of synthetic detergents (and in particular their alkyl benzene sulfonate surfactant components) on sewage treatment processes have been investigated extensively. As of this date, the soap and detergent industry is on the threshold of mass marketing a synthetic detergent containing biologically degradable surfactant ingredients. Hopefully, the industry expects to quiet further complaints that synthetic detergents detrimentally affect sewage treatment operations and cause pollution.

One of the world's largest textile producing centers is located at Dalton, Georgia, in the northwestern part of that state. Washing operations associated with these textile industries are the principal sources of large amounts of synthetic detergents discharged into Dalton's sewerage system. Concentrations of surfactants reaching the municipal waste treatment plant were well above national average.

An investigation was begun in the summer of 1958 to determine the effects, if any, of these synthetic detergents on reportedly poor treatment effected by the plant. The Dalton plant was designed to provide secondary treatment through screening, primary sedimentation, standard

rate filtration, and final sedimentation. Average flow reaching the plant was 5.0 million gallons per day (mgd), most of which was bypassed. The investigation was divided into three phases:

- (1) Phase I - preliminary studies to establish sampling and analysis techniques, to determine sewage quality, and to evaluate the plant's physical features.
- (2) Phase II - studies to determine treatment plant waste removal efficiencies at a flow rate near the designed average rate of 1.5 mgd and at a flow rate of 2.5 mgd.
- (3) Phase III - studies to determine the effect of series, high rate operation of the trickling filters.

The parameters of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were relied upon heavily in the study, but other analyses such as dissolved oxygen (DO), chloride, and anionic surfactant determination were also performed in the treatment plant laboratory.

Results of the investigation revealed that anionic surfactants reached the plant in concentrations as high as 36 parts per million (ppm) and averaged 25 ppm. Total removal of BOD and COD through the plant varied little at different flow rates and with changes in operation, i.e. substitution of high rate, series trickling filter operation for existing parallel operation. Total BOD removal averaged only 66 per cent and COD removal averaged approximately 70 per cent. Numerous deficiencies in plant design, construction, and operation were discovered during the course of investigations.

The principal conclusion of the study was that Dalton's sewage treatment problems were due primarily to a combination of overloading,

and design, construction, and operation deficiencies. Detrimental effects of high synthetic detergent concentrations were not conclusively related to any waste treatment difficulties. The investigator felt that synthetic detergents did aggravate waste removal problems but only to a minor extent. The recommendation was made that, if possible, further studies should be pursued at a time when synthetic detergent concentrations were minimal.

CHAPTER I

INTRODUCTION

Although important research involving the use of surface active agents (or surfactants, as they are called) in washing processes was being performed as early as 1937 (1), it was not until the end of World War II that such names as "TIDE" and "FAB" became familiar to the American housewife. Synthetic detergents, of which surfactants are the essential ingredients, proved to be a boon to everyone concerned with washing processes. The primary reasons for the replacement of synthetic detergents for soaps as the most popular cleansing agents are twofold. First, synthetic detergents, or syndets, do not convert to insoluble fatty acids (which have no detergent power) in acid or neutral solutions as do soaps. Second, synthetic detergents are immune to the effects of hard water which causes soaps to react with calcium and magnesium salts to form greasy curds.

The popularity of syndets spread so that by 1961 the sale of synthetic detergents in this country amounted to 3,469,114,000 pounds compared to 1,014,483,000 pounds of soap sold (2). More than 85 per cent of synthetic detergents sold were used in the household. In spite of this gracious reception for syndets by the public, the sanitary engineering profession viewed with increasing alarm the reported effects of syndets on waste treatment plant operation, ground water contamination, and domestic water supplies. Syndets have been blamed for a variety of ills at waste treatment facilities, including foaming and reduced efficiency

of secondary treatment processes. Contamination of well waters by syndets has also been reported repeatedly within recent years. Even foaming water from household taps has been reported.

Most of the problems associated with synthetic detergents have been attributed to the ability of certain varieties to resist chemical hydrolysis and microbial decomposition--two processes which cause soaps to deteriorate a short period after discharge to a waste stream.

Synthetic detergents as they are marketed today include a variety of ingredients which impart specific characteristics to any particular product. Foam stabilizers are added to some products as well as perfumes and bleaches. All products contain a builder and of course a surfactant. The former is usually a sodium sulfate, sodium polyphosphate, sodium silicate or a combination of these. The builder is responsible for enhancing the cleansing action of the surfactant. Cohen (3) lists some of the components of four common synthetic detergents in Table 1.

Surfactant molecules in syndets have relatively insoluble long hydrocarbon chains and a smaller soluble atomic group. Depending on the electrical charge on the long chain, surfactants are classified as anionic, cationic, or nonionic. The most common type of surface active agent used in syndets in this country is alkyl benzene sulfonate (ABS), an anionic type. Some syndets, notably those which are derived from a fatty acid or alcohol will decompose in much the same manner as soaps. This is not true of ABS which is a petroleum derivative. This compound, which may be described as a saturated, highly branched hydrocarbon which ends with a quaternary carbon to which is attached a benzene ring, has been shown to resist biological degradation (4). Because of this

Table 1. Common Synthetic Detergent Components

Component	Detergent Type			
	A	B	C	D
	Amount - Per Cent			
Alkylaryl sulfonate	9	18	8	31
Alkyl sulfate	9	--	22	--
Sodium polyphosphate	50	47	--	--
Sodium silicate	7	7	--	--
Sodium sulfate	18	23	63	62
Moisture	5	3	5	5
Other compounds	2	2	2	2

resistance trait, the ABS type surfactant has been credited with creating many ill effects in waste treatment processes.

Although the problem of syndet pollution is widespread in this country, there is one municipality in the northwest corner of Georgia which has a particularly high concentration of syndet in the waste waters emanating from its industries and homes. The town, Dalton, Georgia, has been called the "World's Tufted Textile Center." Approximately 30 plants in Dalton manufacture chenille bedspreads, bathmats, rugs, robes, and various other textile products. In addition to the normal number of laundering facilities associated with a city of 17,900 people, there are privately-owned and plant-associated laundries which specialize in cleaning textile products produced in the area. Sewage reaching Dalton's waste treatment plant contains large amounts, in excess of 36 parts per million (ppm) at times, of anionic surfactants which are discharged from laundering facilities. Figure 1 illustrates the location of the municipal waste treatment facility in relation to some of the major waste producing industries.

Dalton is separated into two watersheds and only that portion of sewage which drains from the west and southern area of town is treated at the municipal waste treatment plant. In the summer of 1958, a research project reported in this paper was initiated at Dalton. The purpose of the project was to determine the effects, if any, of relatively high surfactant concentrations on operation of the municipal waste treatment plant. The past records of waste removal efficiencies at the plant had indicated that it was not operating properly.

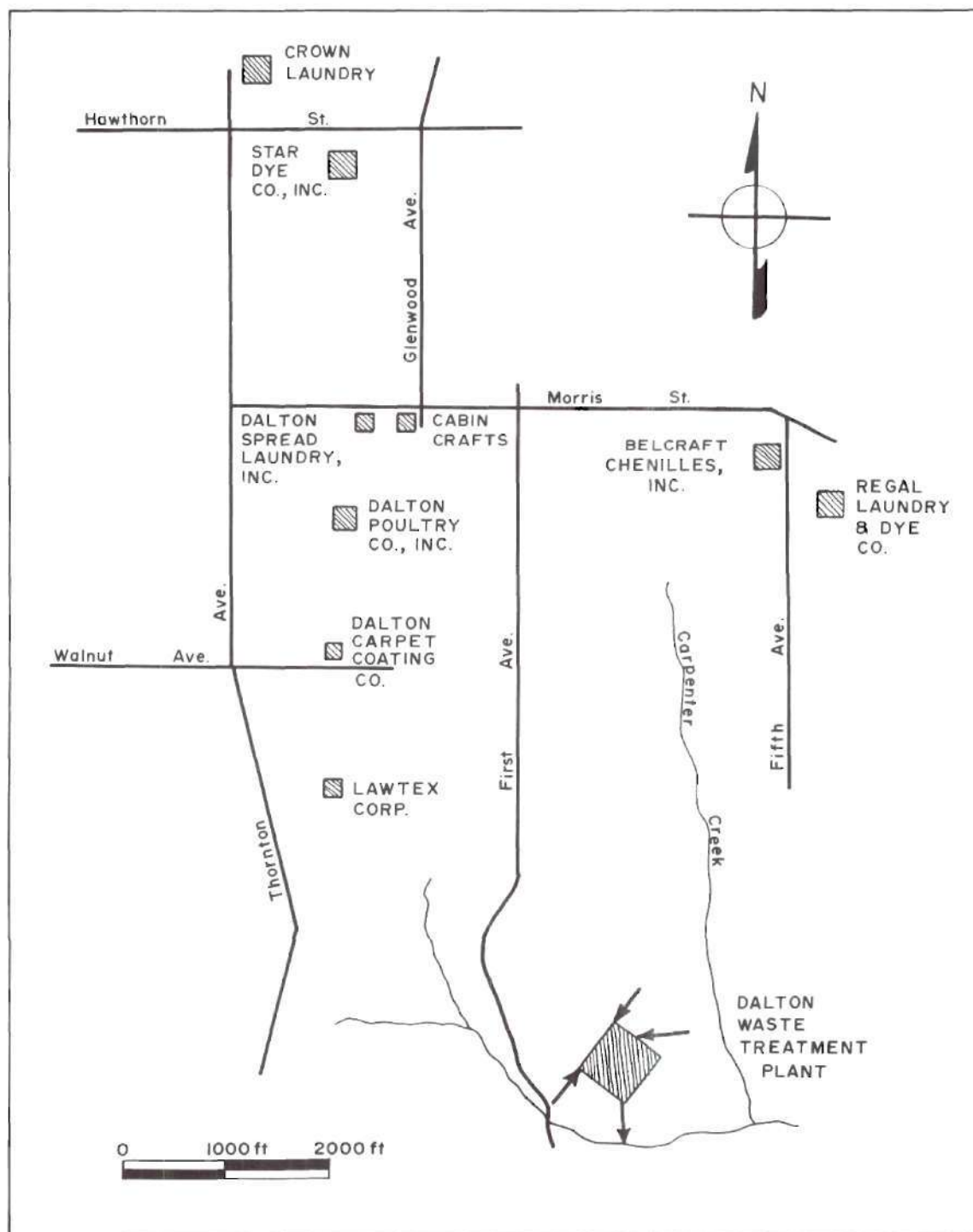


Figure 1. Dalton Waste Treatment Plant Location.

CHAPTER II

HISTORICAL REVIEW

1930 to 1951

The sale of synthetic detergents in quantity began during the late 1930's, and by 1952, syndet sales exceeded those of ordinary soaps. Research in 1937 (1) mentioned previously, hinted at the coming importance of sodium alkyl sulphates as detergents and wetting agents. This study also indicated that the presence of sodium and calcium salts had the effect of lowering surface tension beyond that actually obtained in a pure sodium alkyl sulphate solution. In 1941, Lenher (5) listed hundreds of practical uses for wetting agents which tended to account for their increasing acceptance by the industrial and household market. The listing included uses ranging from raw wool scouring and feather washing to ingredients for depilatory creams and green fodder preservation.

Research concerning the theory of and uses for synthetic detergents continued during the war years. Then, in 1947, the first incidence reported in this country of syndet interference at a sewage treatment plant appeared in the periodical American City (6). It was stated that large amounts of suds two to five feet thick had suddenly appeared in the aeration tanks of the Mt. Penn, Pennsylvania, sewage treatment plant. The foam was said to have caused a "poor condition" in the activated sludge and to have left grease deposits on the walls. On the day previous to this occurrence, samples of a new washday product, a synthetic detergent, had been distributed to homes in the area. Prophetically,

the plant operator urged that discretion be exercised in the future use of syndets.

While sanitary engineers in this country were beginning to study syndet problems with increasing fervor in the late 1940's, these problems were also being investigated in Europe. Sciver's (7) studies suggested that 100 ppm of Teepol, an anionic detergent containing 20 to 21 per cent sodium secondary alkyl sulfates, increased turbidity and oxygen consumed of settled sewage. While some of his tests indicated no effect of syndets on sedimentation processes, others showed improved sedimentation. Concentrations of 40 and 100 ppm had a progressively adverse effect. Another laboratory investigation made in 1949 by Degens (8) et al. concerned relationships of certain surfactants on sewage sludge digestion. Results indicated that amounts of sodium secondary alkyl sulfate, sodium primary alkyl sulfate, alkyl aryl sulfonate, and a polyglycol ether of alkylated phenol up to 500 ppm produced no significant difference in the volume of gas produced. A decrease in methane produced due to replacement of syndet for more readily digestible soaps was predicted however. Another significant conclusion drawn by the Degens study was that sewage could contain 25 ppm sodium secondary alkyl sulfate without the concentration in sludge exceeding 500 ppm. Evans and Winsor (9) contributed syndet study data that showed no apparent effect on sedimentation of unacidified sewage by 40 ppm of sodium secondary alkyl sulfate (as present in Teepol).

One of the earliest important studies in America of syndet effect on sewage treatment was made by Rudolfs, Manganelli, and Gellman (10) in 1949. Some of their conclusions were that syndets ordinarily marketed

at that time affected sewage treatment processes in varying degrees depending on the type of surfactant. Principal effects were: (1) decreased efficiency of settling tanks (syndet concentrations increasing from 0 to 100 ppm) with consequent increased load on trickling filters, (2) foaming and floc agglomeration in activated sludge units, and (3) decreased grease removal throughout the plant.

In 1950, several studies and incidents concerning syndet effect on water supply and treatment as well as on waste treatment were reported. A panel discussion of the Central States Sewage Works Association (11) reported that low solids concentration in aeration tanks increased frothing problems; and frothing in trickling filter drains was being noticed more frequently. Degens and others (12) reported syndet effect on certain water fauna and concluded that alkyl aryl sulfonate did not decompose biologically. They also showed that some surfactants are toxic to tadpoles, sticklebacks, and *Daphnia* at concentrations of 5 ppm. From England, Goldthorpe and Nixon (13) reported that 40 ppm of an anionic surfactant caused ponding of trickling filters after four months operation. A fellow countryman, Hurley (14), in experiments at the Coven Heath Works in Wolverhampton, suggested that Teepol, 20 per cent sodium secondary alkyl sulfate, at concentrations of approximately 120 ppm (24 ppm active surfactant) had no perceptible effect on any part of the trickling filter plant, and that it was almost completely removed during the treatment process. Hurley's work tended to corroborate earlier investigations (9) which showed little detrimental effect of Teepol on sewage treatment at concentrations of 25 ppm or less of active surfactant.

At the 119th national meeting of the American Chemical Society in 1951, three important papers concerning detergents in sewage were presented. A presentation by Rudolfs and Manganelli (15) stated that anionic and nonionic surfactants did not interfere with sewage oxidation, but that cationic types retarded oxidation; sedimentation was reported to be impaired. Claire N. Sawyer's (16) paper reported increasing phosphate content in sewage which caused critical nutrient levels to be exceeded. The third paper, "Effect of Detergents on Slime Growths in Sewers" by Rudolfs and Crosby (17), indicated that Ceepryn, a cationic detergent, retarded slime growth materially and that Nacconol NR, an anionic detergent, stimulated growth in concentrations of 10 to 50 ppm and retarded growth at 100 ppm.

Another meeting at which were presented several views on detergent problems was the 23rd Annual Meeting, Federation of Sewage and Industrial Waste Associations (18). A report on research from the Lawrence Experiment Station in Massachusetts indicated little, if any, effect on sedimentation by the syndets, Hexolate (anionic) and Dreft (30 per cent keryl benzene sodium sulfonate), in concentrations up to 100 ppm. The consensus of opinion of those reporting at this meeting was that syndets in common use at that time were more of a nuisance due to frothing than a true deterrent to effective sewage treatment.

Frothing

As research on syndet relationship to waste treatment processes continued after early investigations in the late 1940's and early 1950's, numerous accounts, in addition to those listed previously, were recorded concerning the frothing nuisance in treatment units. Although it was

discovered during the initial research investigations at Dalton, Georgia, that frothing problems were insignificant, a summary of accounts of the problem and its control are presented here for purpose of historical review.

Foaming in the aeration unit at a Corpus Christi, Texas, waste treatment plant (19) was said to have killed grass and shrubs and created visual unsightliness. Foaming problems were controlled there by using effluent water sprays to break down the froth. At Motherwell, England (20), the intermittent spraying of small quantities (0.11 ppm) of mineral lubricating oil was employed to reduce frothing in aeration tanks. Solids concentration variation failed to be effective. Wells and Scherer's (21) 1952 studies in Texas, however, illustrated that frothing in aeration units was dependent on suspended solids content; the more severe foaming conditions usually occurring at suspended solids concentrations below 1400 ppm. Their research also indicated that addition of Tide, an ABS type anionic syndet, into aeration units at low solids conditions did not aggravate foaming.

In 1954, Degens (22) summarized past accounts of froth problems. His paper, which included reference to many previous studies, reported that frothing seemed peculiar to the diffused air process and that foaming began at outlet ends of aeration tanks and developed toward inlets in some instances and vice versa in others. Froth was usually most voluminous in late evening and early morning. Since foaming problems had occurred with greater frequency since World War II, the presence of syndets, Degens presumed, was one of the major causes of frothing. Again, Degens suggested that frothing was related to solids concentration,

and since frothing usually occurred after two to three hours of agitation, a material or compound may be formed which caused foaming. Some proteins and glucocides were known to form the most stable foam in existence.

Concerning foam suppression, Degens proposed three different methods. The initial choice should be to control solids content within ranges dictated by plant conditions. If this was unsuccessful, a water spray system or defoaming agents such as "S/V Foamrex W" (Socony Vacuum Oil Co.) or "Dow Corning Anti Foam A" might be successfully employed. Berg (23) reported that use of defoaming agents costs approximately \$0.50 to \$1.00 per million gallons of sewage treated.

After the Degens review was published in 1954, no significant new studies on the theory, effect, or control of foaming were reported until Bogan and Sawyer's (24) account in 1956 on relationships between biological degradation and froth persistence. Their research concerning the nine major surfactants then being marketed, three of which were alkyl benzene sulfonates (ABS), revealed that frothing characteristics were related to chemical constitution. There was considerable divergence in degree of frothing among those surfactants tested. Furthermore, the persistence of foaming reportedly was related closely to surfactant susceptibility to biological degradation. Alkyl sulfates lost their frothing ability within six hours while an ABS type continued frothing after 120 hours contact with activated sludge. Bogan and Sawyer's research data also included evidence that biological liberation of surfactant molecules from organic solids prepares activated sludge for frothing. A fourth conclusion stressed by the pair was that presence of the more resistant

surfactants was conducive to frothing. Perhaps the most important finding reported in this study was that there was a difference between frothing characteristics of major surfactants. In light of Bogan and Sawyer's research, it might be shown that previous researchers (21)(25) who tended to show that synthetic detergents played a minor role in foaming problems were possibly testing surfactants with low frothing tendency and persistence.

A short time after the above research work was reported, another study (26) confirmed many of the Bogan and Sawyer study conclusions. In 1957, work of Munro and Yatabe (27) showed that some surfactants have high initial foaming values which soon decrease, but which may increase again after prolonged aeration. One of the last significant studies on the evaluation of frothing in sewage treatment plants was performed at the University of Wisconsin in 1958. Polkowski and others (28) concluded that ABS concentration was a major factor in frothing problems. In addition, they also observed that free ABS concentration varied inversely with suspended solids concentration. This second conclusion tended to account for the success of controlling foaming in aeration units by increasing solids content.

From the studies made to date, this writer concludes that the cause of frothing in sewage treatment plants as well as effective means of control are relatively well known. ABS surfactants appear to be the principal causative agents.

1952 to 1956

To continue with the chronological review of syndet relationship to sewage treatment, excluding foaming problems, Eliassen (29) purported

that anionic detergent types were the most significant in sewage treatment. Furthermore, he stated that since syndets hold dirt in stable suspensions, sedimentation will not be efficient. Work by Meader and Hies in 1952 (30) supported Eliassen's statement on dirt adsorption and also concluded that the effect of added salts in the cleaning solution increased the magnitude of adsorption.

Further study by Manganelli (31) was reported in 1952. His research on the major surfactants and their effect on sewage treatment re-emphasized that anionic detergents do not appreciably interfere with oxidation processes in concentrations up to 100 ppm of syndet (surfactant content of 20 to 30 per cent). Manganelli, then, felt that syndets being marketed were primarily of nuisance value only. Studies at the District of Columbia Sewage Treatment Plant (32) supported Manganelli's thinking. However, conflicting studies in England (33) with different types of synthetic detergents showed reduction in settling efficiency up to ten per cent, detrimental effects by some syndets on biological processes, and poor sludge digestion in the presence of high syndet concentration.

Aside from expected disagreement between sanitary engineers and detergent manufacturers as to syndet effects, there were during the early 1950's obvious conflicting opinions among the sanitary engineers themselves. Some of the researchers supporting the view that synthetic detergents have detrimental effects on some sewage treatment processes, in addition to those mentioned previously, were Lumb (34), Isaac (35), and Rudolfs (36). Opposing views were expressed by Gowdy (37), Flett and Hoyt (38), and Lehberg (39). Finally, in 1954, the preliminary

studies of Bogan and Sawyer on biochemical degradation of syndets (40) offered a plausible explanation for previous opinion differences. This work indicated considerable variation in susceptibility to biological degradation among surfactants of the same chemical type and also among different classes. Alkylaryl sulfonates and ABS types introduced in 1950 were among the most resistant. Sawyer collaborated with Lynch (41) in another research report which concluded that most surfactants and especially ABS types reduce oxygen transfer rates during aeration.

Continued study results from Bogan and Sawyer (42)(24) published in 1955 and 1956, consistently pointed toward ABS type surfactants as the true "troublemakers" so to speak. The 1955 study revealed that branching of the alkyl group markedly reduced syndet amenability to aerobic assimilation; a conclusion also reached in England by Hammerton (43).

Subsequent to the research of Bogan and Sawyer, a number of studies in this country and elsewhere supported the more popular view that ABS surfactants were deleterious in waste treatment processes. From England, Lockett (44) reported ill effects, i.e. foaming and decreased biological purification, attributed to the presence of ABS type synthetic detergents. Manganelli's (45) research recorded in 1956 concluded that the adverse action of syndets on activated sludge involves the degradative mechanisms, and that a decrease of pH in aeration tanks increased the suppressive action of an ABS surfactant tested. Again from England, Raybould and Thompson (46) presented the interesting conclusions that Tide, 20 per cent active ABS, was more troublesome than some syndets, but that synthetic detergents in general should not cause undue troubles in trickling filter plants.

1957 to Date

In 1957, Barden and Isaac (47) reported extensive research results concerning syndet effect on trickling filter performance. They concluded that overloaded plants were more detrimentally sensitive to syndet presence than other plants; that suppression of oxygen transfer rates is the most likely detrimental effect of syndets (particularly ABS types); and that BOD removal was increasingly affected as syndet concentrations exceeded 20 ppm. Furthermore, Messrs. Barden and Isaac suggested that variation of loadings employed by research workers in the past was the reason for the diversity of results obtained.

McKinney (48) summarized synthetic detergent effects reported prior to 1957. He showed that average sewage contained 10 ppm surfactant, only half of which was ABS. Throughout his review, McKinney indicated that past research had not definitely proved that syndets were the sole cause of frothing or that reduced efficiencies of primary tanks were due to syndets. It was concluded that further research was needed on all phases of syndet effects.

Research reported during and after 1957 again presented varying conclusions relating to syndet (ABS types in particular) effects. Some researchers tended to minimize again the problems alleged to be caused by syndets. Notable among this group were H. Mann and D. W. M. Herbert (49); F. J. Coughlin (50); R. H. McGaughey and S. A. Klein (51); Malaney, Sheets, and Ayres (52); and P. J. Weaver (53). Those who stressed the significance of relations between decreased waste treatment efficiencies and the presence of syndets included Downing and Scragg (54), C. N. Sawyer (55), and Hernandez and Bloodgood (56).

From studies performed by the "problem minimizing" group, a number of noteworthy results were reported. Mann and Herbert (49) in 1957 showed that 53 to 77 per cent of anionic syndets were removed by trickling filters. As reported by McGaughey and Klein (51), ABS in concentrations of 10 to 15 ppm failed to cause activated sludge, trickling filter, or sedimentation units *to perform other than as designed*. They further indicated that settling removed 10 to 12 per cent of applied ABS, and that total plant removal varied between 19 and 77 per cent. The Malaney, Sheets, and Ayres (52) investigations in 1960, revealed that anionic surface active agent (ASAA) concentration increases were associated with increased BOD removal in aeration units.

The researchers mentioned above who viewed syndet effects as deleterious also reported significant findings. One of the most prominent of these findings was C. N. Sawyer's (55). His report in 1958 indicated that while suspended solids removal was not measurably affected by ABS, the other effects of ABS were to cause frothing, to possibly create toxic conditions in digestors, and to reduce overall plant efficiencies (especially as design capacities were approached or exceeded). Sawyer further stated that the alkyl sulfate detergents were biologically soft, and the ABS type because of their "hard" qualities escaped treatment plants in significant amounts. Ludzack and Ettinger (57) were to show in 1960 that no syndets were biologically inert, but that the ABS types were more resistant.

Literature Research Conclusions

Only a representative portion of the myriad of publications on

synthetic detergents effects have been discussed. The problem of major concern now is one of deciding with which of the reporting groups to side--those who relegate the significance of syndet effects or those who have shown a definite causal relationship between syndet presence and waste treatment plant operation difficulties. The two groups are not split into industrial interest and sanitary engineering factions as might be expected. In fact many members of the sanitary engineering profession hold the same views as most industrial researchers, i.e. that syndets do not significantly affect waste treatment processes. Certainly, competent investigators are represented in both factions, but their objectives and study methods varied considerably.

This writer believes that there is more than reasonable evidence to support the view that surfactants, notably those of the alkyl benzene sulfonate group, can detrimentally affect many waste treatment processes. Sawyer's and Bogan's several studies are cited as important supporting arguments. The extent to which ABS affects the treatment process is still relatively undefined, even after literally hundreds of investigations since the end of World War II. The fact that many types of surfactants have been studied under widely varying experimental conditions has accounted for many of the conflicting results reported in the past.

At the present time, the major portion of research work being performed is not pointed at further definition of the syndet problem. Methods of surfactant removal such as activated carbon application reported by Lieber (58) are being studied. And, at the insistence of water pollution regulatory agencies in this country and especially in Europe, new, biologically degradable surfactants are being examined, and

in some instances, marketed. While marketing of the new syndets has not yet begun in earnest in this country, it is felt that it is now only a matter of time. If the new products are accepted by the public, their effect on waste treatment and foam problems will need to be investigated further. Perhaps additional problems will be created, but these could not possibly be as esthetically unacceptable as having foamy water issue forth from the kitchen faucet.

CHAPTER III

DALTON'S WASTE TREATMENT PLANT

The research work reported by this writer was performed at the Dalton, Georgia, sewage treatment plant. Figure 2 is the flow diagram of the plant as it existed prior to initiation of the investigation. As shown, the plant was a secondary treatment type, incorporating standard rate trickling filters as biological treatment units. Prior to entering the plant proper, the municipal and industrial wastes originating from the west and southern areas of Dalton flowed into a collection manhole. Sewage entered this manhole from three directions and in amounts approaching an average dry weather flow of five million gallons per day (mgd). Fortunately a bypass outlet had been provided for diversion into nearby Carpenter Creek of flows exceeding plant capacity. As the plant was designed for an average flow of 1.5 mgd and a daily peak flow of 3.0 mgd (200 per cent of average), large amounts of untreated waste were discharged through the bypass outlet. Figure 3 shows bypassed sewage spilling down the outfall apron into the creek; a color contrast is apparent. Foaming caused by high surfactant concentration was never a problem at this point.

After leaving the collection manhole, sewage flowed through a flow control structure and into the wet well. Prior to pumping into the primary settling basin, large solids were removed by a bar screen or were reduced to settleable size by a comminutor. The comminutor was

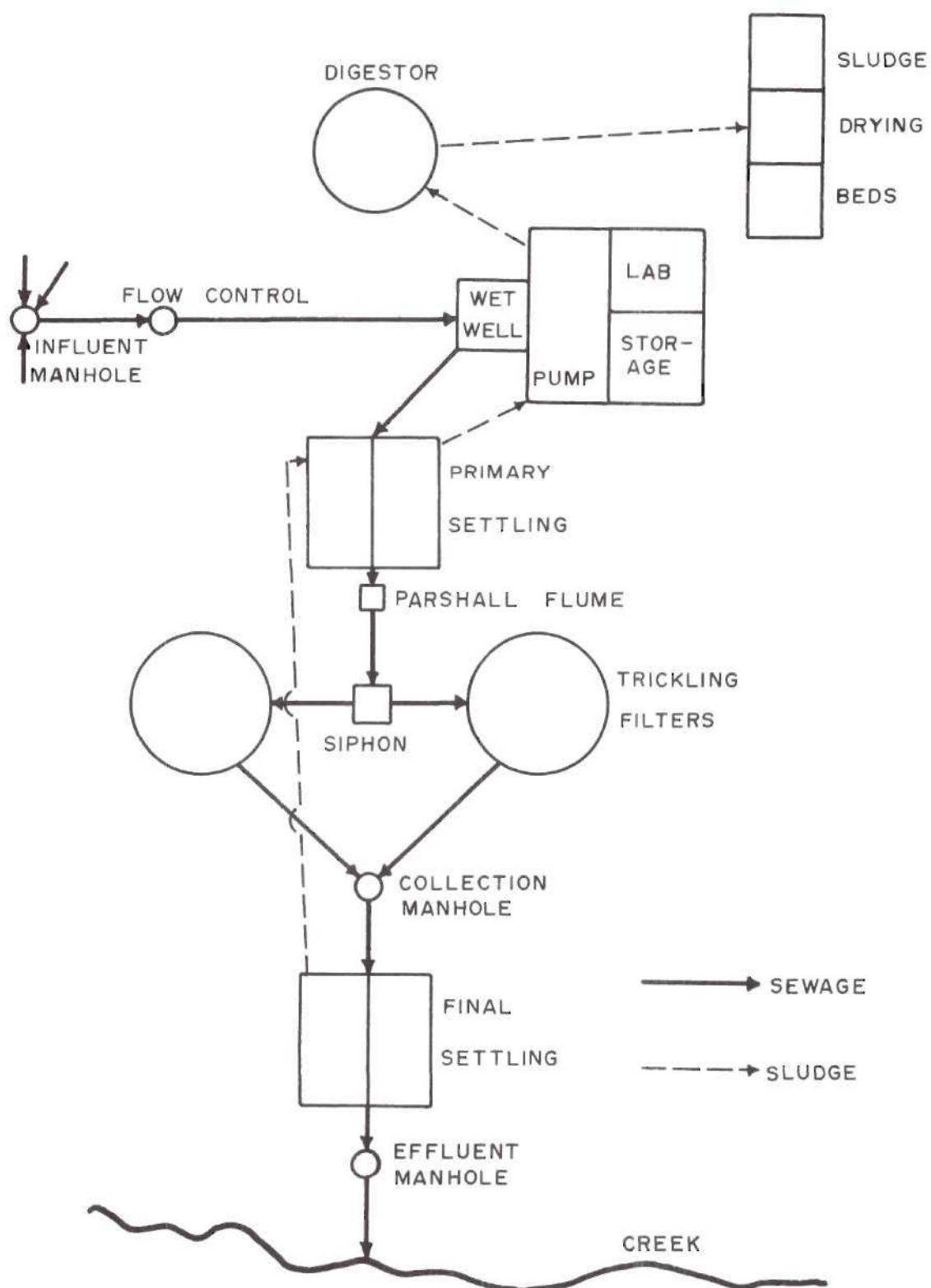


Figure 2. Flow Diagram--Dalton Treatment Plant in July 1958.



Figure 3. Sewage Bypassed to Carpenter Creek.

inoperative throughout the 1958 period of study. (This deficiency together with other design, construction, and operation deficiencies of the plant will be discussed in a later section.) A view of the wet well from above is presented in Figure 4. The bar screen may be seen in the lower right corner of this illustration.

Sewage was pumped by one to three pumps from the wet well to the mechanically cleaned primary settling basin. The basin was ten feet deep and had a volume of approximately 21,000 cubic feet (157,000 gallons). The surface area was slightly in excess of 2100 square feet, and settled sewage flowed into outlet channels with over 72 feet of weir length. Capacities of the primary sedimentation units were calculated by using Great Lakes-Upper Mississippi River Board of State Sanitary Engineers sewage works standards, or so-called "Ten State Standards." For the primary settling tanks, a surface loading of 900 gallons per day per square foot (gpd/sq ft), a detention time of two hours, and a weir loading of 15,000 gpd/ft were utilized to calculate capacities. Computations indicated that the primary settling capacity was 1.9 mgd based on surface loading, 1.9 mgd based on detention time, and 1.1 mgd at the selected weir loading rate. Thus, weir loading appeared to be the limiting factor.

After leaving the settling basin, sewage flow was measured in a Parshall flume section. From this point the sewage discharged into twin siphon chambers designed to control the application rate on the two trickling filters. The filters were designed as standard rate and each had a diameter of 118 feet with a 6.25 foot depth. Accepted surface hydraulic loading rates for standard rate trickling filters vary between

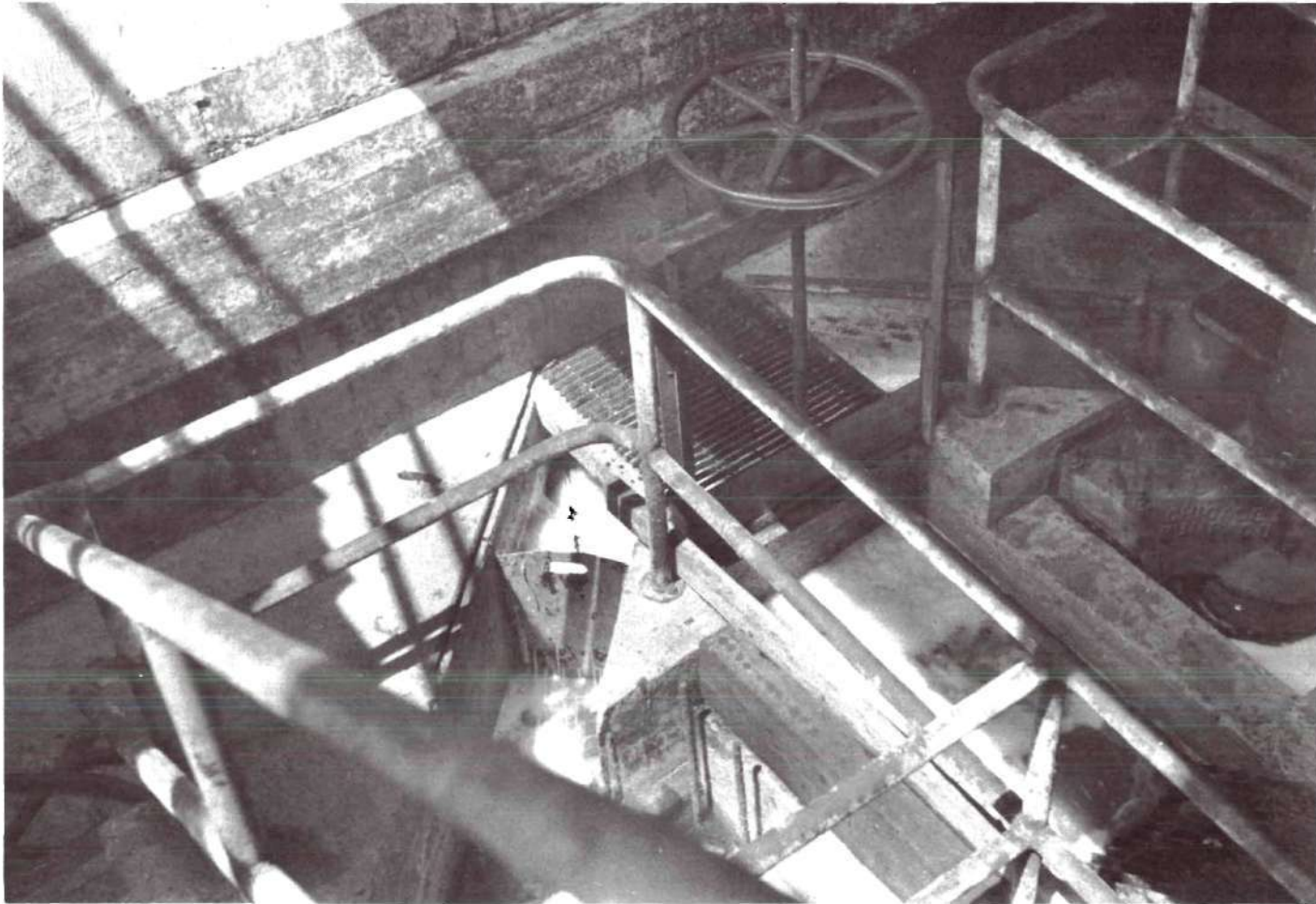


Figure 4. Wet Well (Bar Screen in Lower Right Corner).

two and four million gallons per acre per day (mgad). Using a four mgad loading rate, the filters' capacity was computed to be two mgd. However, at a volumetric hydraulic loading of 400,000 gpd/acre-foot (normal variation between 200,000 and 600,000 gpd/acre-foot), the capacity of the two filters was estimated to be only 1.25 mgd.

Having received both primary settling and biological filtration, the sewage next flowed into the mechanically cleaned final settling basins. These basins had approximately the same surface area (2140 square feet) as the primary units, but with an additional 50 feet of weir length, making a total of 120 feet. Capacity checks of these units using the "Ten State Standards" revealed that at a surface loading of 800 gpd/sq ft, the final settling basins could receive 1.7 mgd. At a weir loading of 15,000 gpd/ft, the capacity was 1.8 mgd. A view of the primary basin and trickling filters is shown in Figure 5.

The preceding analysis of hydraulic capacity of the various units showed that the Dalton sewage treatment plant could accept the average 1.5 mgd design flow rate, but would seriously lose its treatment efficiency if the peak 3.0 mgd design rate were maintained for long periods. Actual sewage flows reaching the plant greatly exceeded even the peak design flow; therefore, there was ample opportunity to evaluate plant operation at various flow rates by control of the inlet gate.

Anaerobic treatment of solids removed by sedimentation was performed in a single digester (Figure 6) having a 53,500 cubic foot volume. Sludge from the final settling basin was pumped into the hoppers of the primary sedimentation basin (Figure 2). From this point, pumps in the control house transferred the sludge to the digester. Heating of the

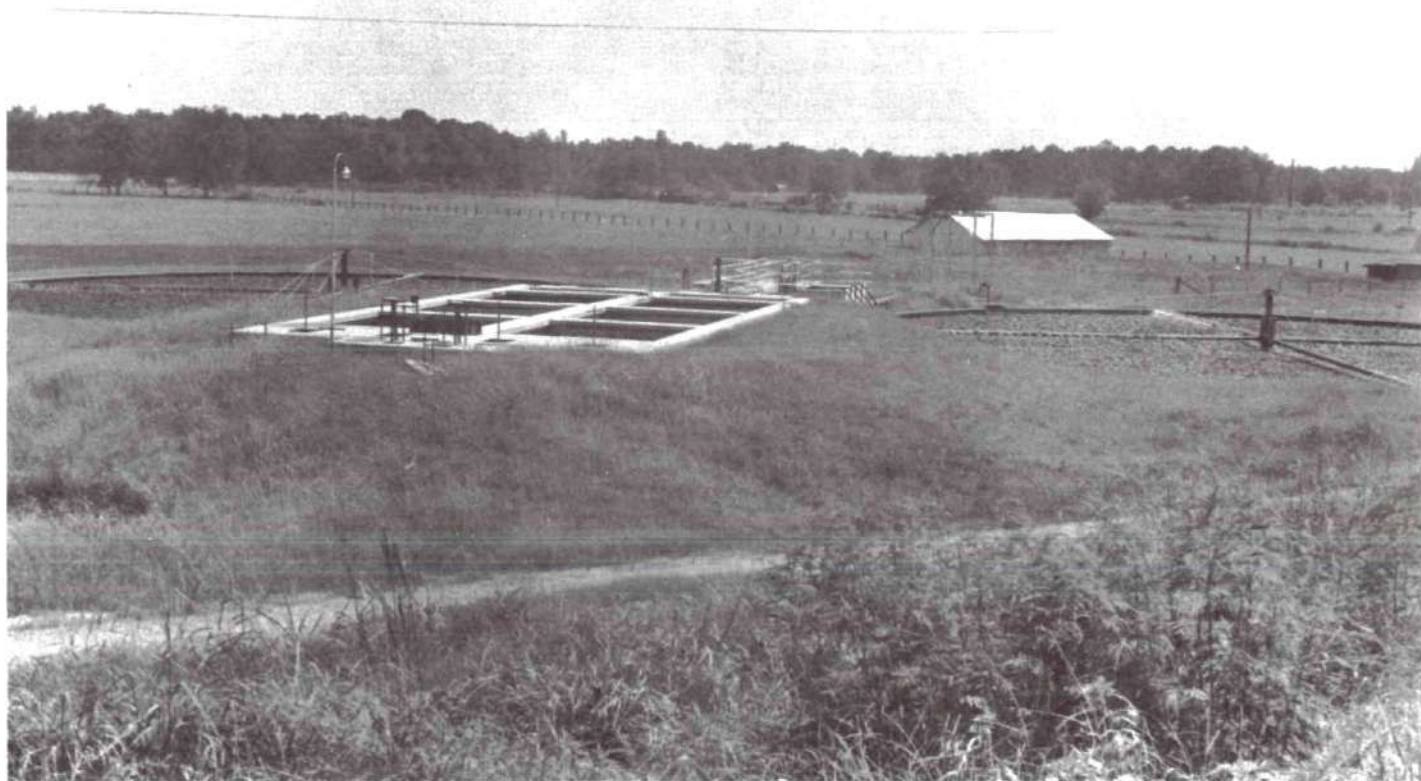


Figure 5. Primary Sedimentation Basin and Trickling Filters.

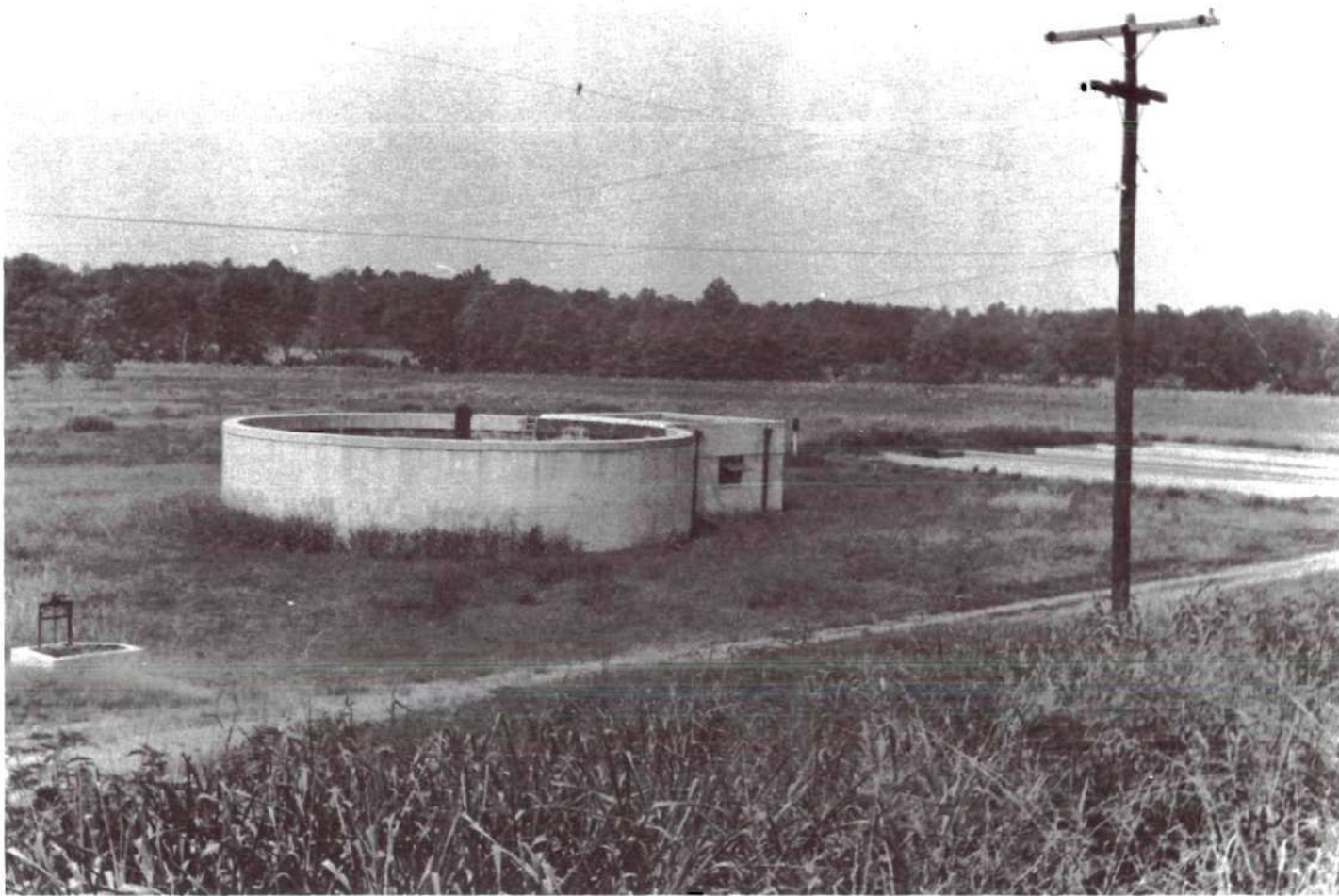


Figure 6. Digester and Sludge Drying Beds.

digester's contents was accomplished through direct warming of sludge recirculation lines by a sludge-gas fueled heat exchanger. The exchanger was also designed to burn fuel oil in the event that sludge gas was not present in sufficient quantities. Approximately 15,000 square feet of sand drying beds was provided for drainage and drying of digested sludge.

As mentioned, the control house (Figure 7) contained sludge pumps and the digester heat exchange unit. In addition the laboratory and shop were also located in this structure.



Figure 7. Control Building.

CHAPTER IV

EQUIPMENT FOR LABORATORY STUDIES

In the early planning stages of the investigation, it was determined that the laboratory facilities at the Dalton sewage treatment plant would be utilized to the greatest extent possible. An inventory of the available supplies and equipment revealed that a majority of basic items needed were present, but some major equipment was lacking. There was no operative BOD incubator in the lab as well as no photometric instrument to be used for certain colorimetric analyses. Although a 20° C incubator was eventually purchased by the City during the latter part of the investigation, it was not possible to procure either a spectrophotometer or a colorimeter for use at the laboratory. Photometric equipment was desirable because of its greater versatility and accuracy when compared to Nessler tube techniques. The absence of this equipment necessitated modification of one of the major analysis procedures. This will be discussed in CHAPTER V.

Much of the basic equipment utilized in the study is shown in Figures 8 and 9. The first figure depicts: (1) an analytical balance used to prepare reagents; (2) a conductivity bridge having built-in temperature compensating controls, a range for conductivity of 0.4 to 5,000,000 micromhos, and a scale for direct determination of resistance in ohms; (3) a dessicator used for residue analyses; (4) a drying oven capable of maintaining $103^{\circ}\text{C} \pm 1^{\circ}\text{C}$; and (5) miscellaneous pieces of glassware. Pictured in Figure 9 is the line-operated pH meter and



Figure 8. Laboratory Equipment.

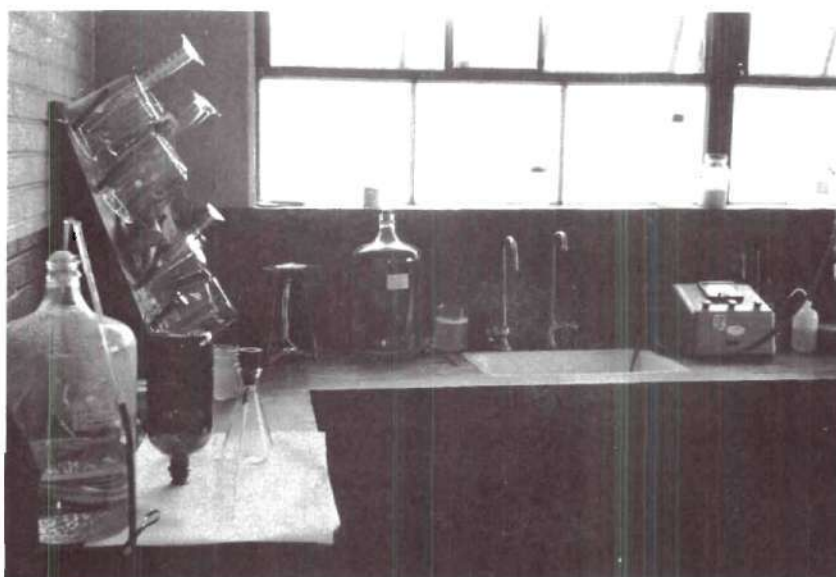


Figure 9. Laboratory Equipment.

porcelain sink. Not shown is the BOD incubator, a 600° C muffle furnace used to determine ash content of sludge solids, and other smaller apparatuses needed for some analyses.

Even though crude by some standards, the laboratory of the Dalton plant was sufficient for the needs of this investigation. Funds were made available by the City to augment depleted supplies and to purchase new chemicals and equipment needed. Some supplies were obtained on loan from the Department of Applied Biology, Georgia Institute of Technology.

Special analysis equipment for the laboratory investigations per se was not deemed necessary. However, the plant itself was altered during the fall of 1958. Recirculation pumps were installed following final settling to provide high rate, two-stage, trickling filter operation. A special study of the recirculation system will be discussed in more detail in a later section.

CHAPTER V

ANALYTICAL AND OTHER STUDY METHODS USED AT DALTON

An investigation concerning effects of synthetic detergents on operation of the Dalton sewage treatment plant was conducted during the period July--November 1958. The investigation may be separated into three distinct phases;

- (1) Phase I--preliminary studies.
- (2) Phase II--study of existing plant.
- (3) Phase III--study of plant after installation of pumps for series operation.

Phase I--Preliminary Study Phase

During the three-week period of July 22 through August 13, 1958, preliminary studies of the sewage treatment plant were made. Sampling and analysis procedures were standardized, data were obtained on the quality and quantity of waste sources, and plant design and operation were observed.

Two major problems relevant to the successful completion of the investigation developed in Phase I. First and most perplexing was the frequent and unpredictable number of plant breakdowns, both minor and major, which occurred. One of these breakdowns rendered practically the entire plant inoperable for several days while others affected only certain treatment units. The causes of these difficulties were many and varied and will be discussed in more detail in CHAPTER VI.

Attempts to obtain knowledge of plant operation when industrial wastes were either absent or minimal met with limited success. Throughout the July--November period, most of the textile and associated industries in Dalton were producing goods at peak production rates. This meant 24-hour per day, 6 days per week operation. A limited number of studies were conducted on Sundays, but the results were inconclusive, possibly due to insufficient plant recovery time.

By trial and error, a sampling procedure was adopted which was applicable for most study conditions. Grab samples were taken during the preliminary phase in order to determine both sewage quality and expected treatment efficiencies at any given time. When it was discovered that quality of the sewage varied greatly from hour to hour, the decision was made to rely on composite samples for indications of treatment efficiencies. Usually these composites were prepared by addition to a large container of 250 ml to 100 ml portions every 15 minutes or half hour for a period of three to five hours. Collection time at the various plant units was staggered to compensate for normal flow-through time. Preservation of the sample during the compositing period was studied. Two methods were tried, one in which no preservative or icing was used, and one in which the samples were preserved on ice. Since no appreciable difference in results was determined between either procedure, the compositing method without ice was adopted.

Another decision to be made concerned time of sampling. Composites were made during both night and day. No significant quality differences were observed, however, and the plant was continuously overloaded hydraulically. Composites were thereafter obtained during

the daytime.

Samples of plant influent were withdrawn from the gate control valve structure; primary sedimentation effluent from the weir overflow trough; trickling filter effluent from the final settling basin influent, or, if for individual filters, from the filter effluent control valve structure; and for the final settling basins (plant effluent) samples were obtained from the final weir overflow trough.

Most of the analyses made during Phase I were considered normal for sewage treatment plant laboratory work. These included the following physical and chemical determinations:

- (1) pH (hydrogen ion concentration).
- (2) Temperature (in degrees centigrade).
- (3) COD (chemical oxygen demand).
- (4) Resistance (in ohms).
- (5) DO (dissolved oxygen) by the Alsterburg (azide) modification.

All of the above examinations were performed according to the tenth edition (1955) of Standard Methods for the Examination of Water, Sewage, and Industrial Wastes (59), published jointly by the American Public Health Association, the American Water Works Association, and the Federation of Sewage & Industrial Wastes Associations.

For the subject investigation, parameter measurements were also added for anionic surfactant, sulfates, chlorides, settleable solids, and other observations and measurements. Sulfate and chloride analyses were included because previous data (60) had indicated high salt concentrations in the Dalton sewage. Both of these determinations were performed according to the tenth edition of Standard Methods.

Analysis for anionic surfactant, which was not then included in Standard Methods, was performed with necessary modifications according to the method of Longwell and Maniece (61). This technique is quite similar to the current methylene blue procedure in the eleventh edition (1960) of Standard Methods (62). Modifications in the surfactant analysis procedure involved substitution of color standards in 100 ml Nessler tubes for direct photometric readings of color development. Admittedly a Nessler tube technique is subject to more error than photometric methods. However, since no colorimeter was available, the procedure was necessarily adapted to a "field type" determination. The problem of deterioration of color standards was overcome through daily calibration and subsequent adjustment in analysis results. Fresh standards were prepared when daily calibration indicated excessive color deterioration.

Some of the conflicting reports cited in CHAPTER II were probably caused by lack of an accurate analytical method for determining anionic surfactants. The methylene blue method used by this writer had its deficiencies also. It was subject to interferences from both organic and inorganic compounds. Some of the reported (62) interfering substances were organic sulfates and phosphates, and inorganic chlorides and nitrates. Because of these interferences and because of further error introduced through alterations in the Longwell and Maniece procedure, the results for anionic surfactant which follow are considered estimates, accurate within ± 2 ppm.

Phase II--Study of Existing Plant

Following preliminary studies ending August 13, 1958, the Dalton

sewage treatment plant as it existed in summer 1958, was studied for the period August 14 through October 2, 1958. Sampling and analysis procedures previously established were utilized to determine possible effects of synthetic detergents on treatment plant efficiencies. With flow rates entering the plant controlled at the gate valve, studies were made of all the major units in the plant. Attempts were made also to study the plant at varying concentrations of surfactant. Considerable time was devoted during Phase II to operation and maintenance of the plant.

Phase III--Study of Plant with Series Operation Features

Conversion of the Dalton waste treatment plant to operate at high rate trickling filter loadings was effected between October 2 and October 22, 1958. High rate loadings are generally considered to lie between 2000 and 3000 pounds of applied BOD per acre-foot per day (lb BOD/ac-ft/day). The high rate performance was obtained by recirculating intermediate settling basin effluent to a chamber of the trickling filter dosing siphon. Thus the revised flow pattern in Figure 10 may be described as follows:

- (1) The entire primary settling basin effluent discharges to Filter No. 1.
- (2) Effluent from Filter No. 1 enters the intermediate settling basin.
- (3) Effluent from the intermediate basin is pumped to Filter No. 2.
- (4) Effluent from Filter No. 2 enters the final settling basin from which it flows into the plant outfall sewer.

NO CHANGE

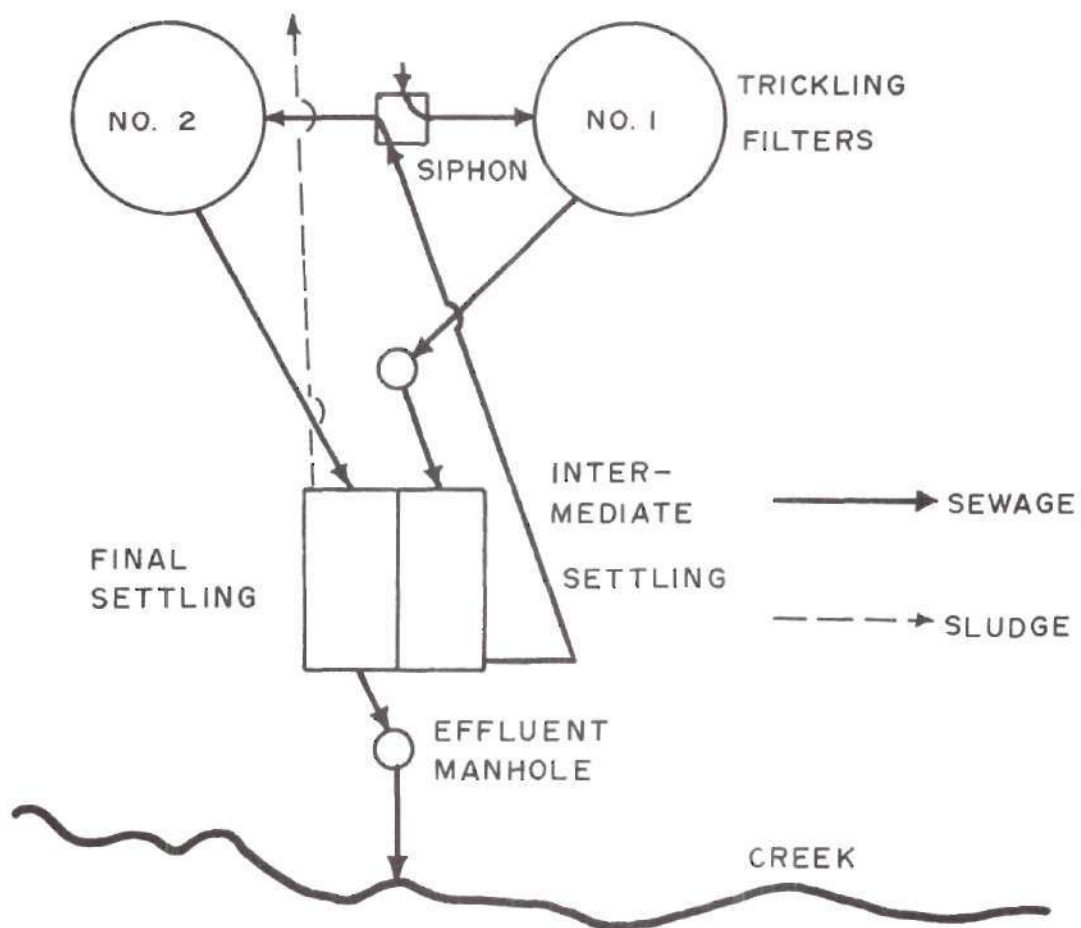


Figure 10. Flow Changes Effectuated for Series Operation.

The appearance of the plant after addition of recirculation features is shown in Figures 11 and 12. Maximum capacity of the pumps shown in Figure 11 was approximately two mgd. The "U. S. Pipe" recirculation line may be seen in Figure 12.

During the final study phase of the Dalton study, plant operation was observed at varying influent rates and with as many different plant conditions as time permitted. The sampling and analysis program was revised only slightly to reflect the alterations effected in treatment. A BOD incubator was available for this final study phase, and results of five-day, 20° C BOD's were compared with COD results for same composites. An effort was made to establish a BOD versus COD relationship in order that previous COD data might be utilized to indicate BOD removal efficiencies.

Phase III studies extended from October 22 to November 30, 1958.

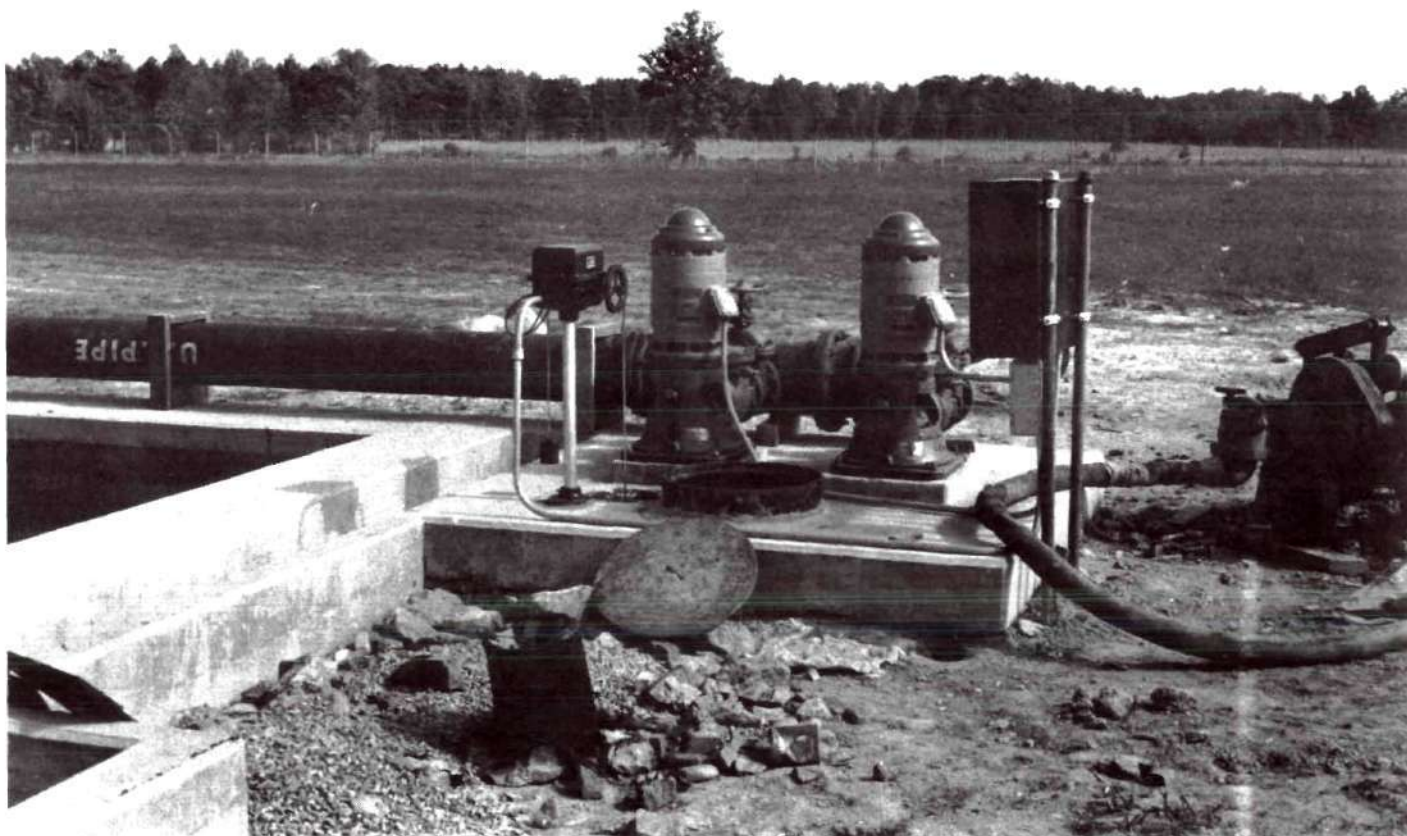


Figure 11. Recirculation Pumps for Series Operation.

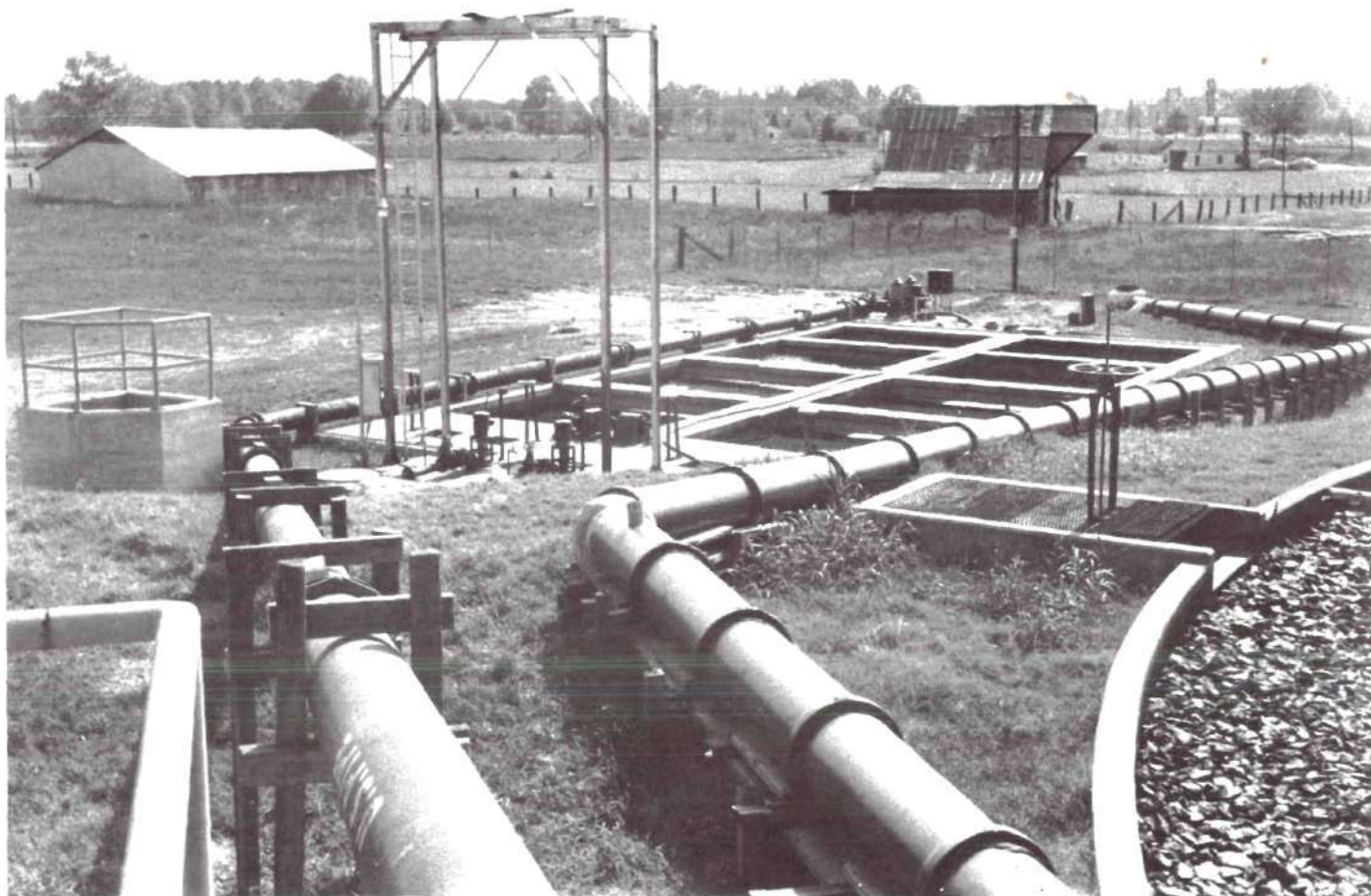


Figure 12. "U. S. Pipe" Recirculation Line.

CHAPTER VI

RESULTS OF THE INVESTIGATION

Data collected during each of the three study phases are discussed below.

Sources of Waste

During the beginning of the study, pertinent data were collected on municipal and industrial waste sources. These data are shown in Table 2. Information obtained indicated that of the total waste flow reaching the Dalton plant, an average of one mgd is municipal and four mgd is industrial. The municipal wastes had an estimated BOD population equivalent (PE)* of 12,000. Industrial waste PE, which varied considerably on a diurnal basis, was estimated to average 50,000. Thus, sewage equivalent to that from 62,000 persons was to be treated in a plant designed to serve approximately 20,000. The largest amount of industrial waste was contributed by textile product manufacturers and associated firms. Some industrial waste (in amounts less than 0.5 mgd) was discharged to the city sewers from a poultry processing plant, service stations, and other smaller industries.

Chenille product and carpet manufacturing accounted for most of the industrial production in Dalton. Typical waste from dyeing operations contained:

*BOD population equivalent assumes that the per capita BOD production is 0.17 pounds per day.

Table 2. Sources of Waste

Waste Source	Average Daily Flow(mgd)	PE (BOD)
Municipal (consisting of wastes from residences and commercial establishments)	1.0	12,000
Industrial:		50,000
Crown Laundry	0.45	
Star Dye Co., Inc.	0.19	
Dalton Spread Laundry, Inc.	0.30	
Cabin Crafts	0.70	
Dalton Poultry Co., Inc.	0.38	
Belcraft Chenilles, Inc.	0.30	
Dalton Carpet Coating Co.	0.65	
Lawtex Corp.	0.30	
Regal Laundry and Dye Co.	<u>0.50</u>	
Total	5.0	62,000

- (1) Anionic detergents.
- (2) Various dyes (including those with coal tar base).
- (3) Salts (for dye fixing).
- (4) Hypochlorite bleach.
- (5) Sodium hydrosulfite (for decolorizing).

Waste from the largest carpet manufacturer was reported to include:

- (1) Anionic detergents.
- (2) Cationic detergents.
- (3) Salt (both sodium chloride and sodium sulfate).
- (4) Sodium nitrite.
- (5) Sulfuric acid.
- (6) Acetic acid.
- (7) Other chemicals in small percentages.

Many of the textile industries used as much as 900 gallons of water for each 100 pounds of manufactured goods.

Study Results--Phase I

Based on grab sample analysis, preliminary studies showed that diurnal variation of influent quality was pronounced. Typical daily results are shown in Figure 13. The illustrated values were characteristic of this first study phase--a period in which influent pH varied from 6.7 to 10.4, resistance from 230 to 800 ohms, temperature from a warm 35° C to a warmer 42° C, and anionic surfactant from 20 to 36 ppm. Although it was known that cationic and nonionic surfactants were also present in Dalton sewage, quantitative determination was considered beyond the scope of this study.

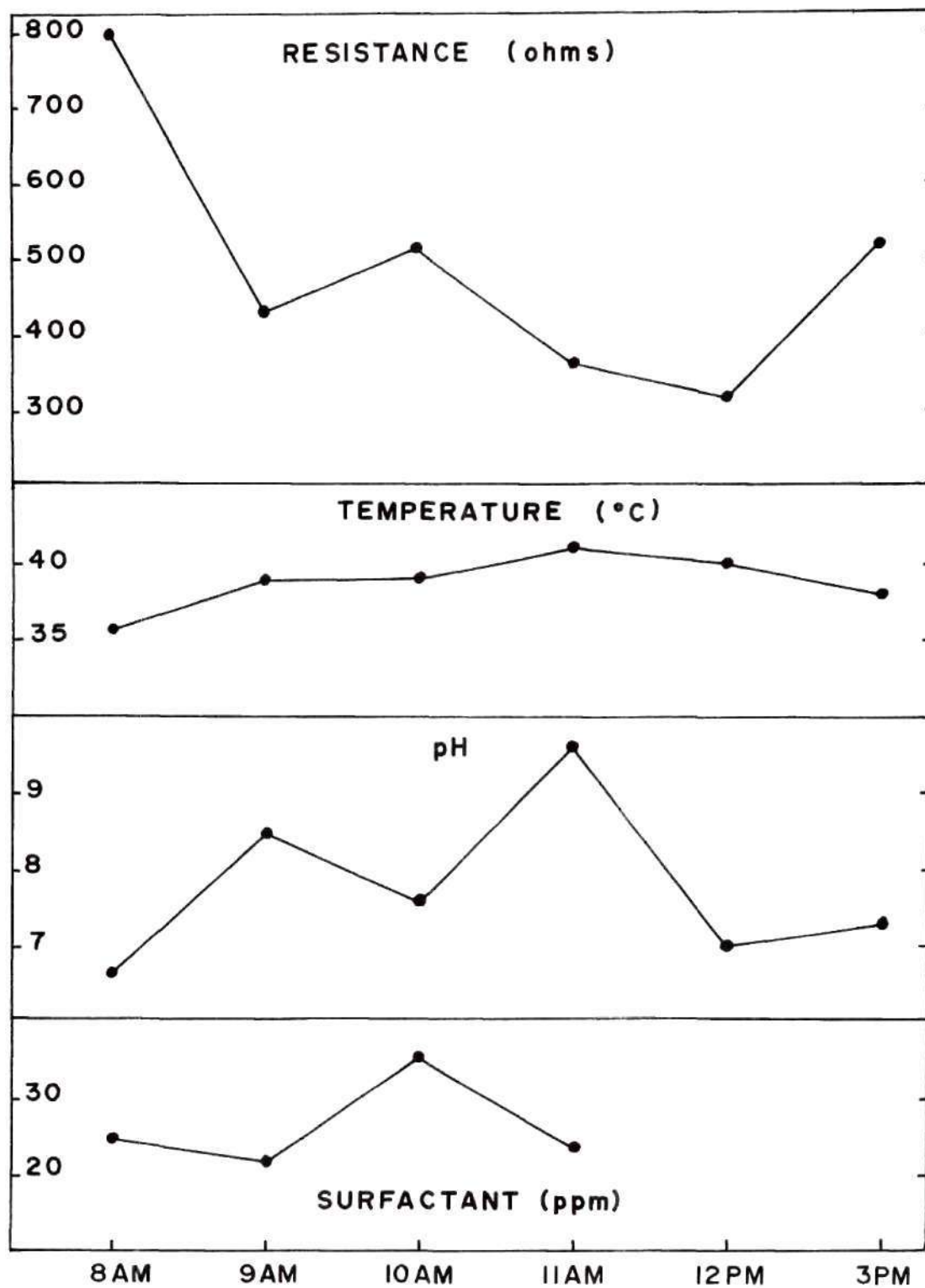


Figure 13. Sewage Influent Quality Variation, August 6, 1958.

Comparing analysis results with average sewage content, one would find that Dalton sewage had a higher pH, higher temperature, and higher concentration of anionic surfactant than even the relatively strong sewage of Europe and England. An effluent COD determination made during the latter part of Phase I showed that the value of this characteristic also exceeded average sewage values. The COD concentration was 217 ppm. The reason for the unusual content of Dalton's sewage was caused by the proportionately large amount of industrial waste.

Plant operation during Phase I was studied at the average flow rate being maintained before this investigation began, namely 2.5 mgd.

In addition to analysis of the above parameters, certain visual observations of plant conditions were made. At an early stage, foaming was determined not to be particularly troublesome. Previous sewage treatment plant studies reported in CHAPTER II had indicated that the foaming problem was almost exclusively characteristic of activated sludge processes. At Dalton, maximum foaming occurred at the outfall on Carpenter Creek. Usually foaming at the plant outfall was much greater than at the bypass outlet, 100 yards upstream. This indicated that the surfactant-dirt particle bond had been weakened enough by treatment processes to allow the surfactant to froth. At times the foam persisted in the stream for a distance of several thousand feet.

Foam resulting from turbulence at the entrance to the wet well occasionally covered the access walkway at the bar screen. Presence of a chlorine odor in the wet well attributed to textile bleachery waste was also quite common.

Another unusual characteristic of sewage entering the plant was

its wide variation in color. As many as three to four major changes were observed within one hour periods. Appendix A, the study data tabulation, shows that tan, green, pink, gray, and blue colors were reported. Actually the sudden color changes proved to be a useful tool, as they could be used to indicate detention time in the primary settling basin. In order to make this determination, the time interval between initial color change reaching the overflow weirs and maximum development of color was determined. Detention time was approximated by:

$$t_d = \frac{t_{\max} + t_{\min}}{2}$$

where t_d = detention time; t_{\max} = time interval between color introduction and maximum development at weir; and t_{\min} = time interval between color introduction and first appearance at weir.

Inasmuch as serious difficulties in establishing digestion had been reported in previous studies at Dalton (63), an analysis of digester sludge was made. The results showed a pH of 7.4 (considered satisfactory for optimum digestion) and a solids content of 6.5 per cent. The per cent solids value indicated incomplete digestion at the time of sampling since well-digested sludge normally has eight to ten per cent solids. The amount of volatile solids was 34 per cent.

Throughout Phase I, gas production in the digester was sufficient to furnish fuel for the heat exchanger. Sludge temperature was maintained at 32°C (90°F) $\pm 2^{\circ}\text{C}$.

Study Results--Phase II

After determining study techniques and waste characteristics in Phase I, investigations were shifted to Phase II, determination of operating efficiencies of the existing plant and effects of surfactants. Studies performed during Phase II were conducted at essentially two flow rates. The 2.5 mgd rate maintained in the first phase was continued during August, and a flow of 1.7 mgd, approximately equal to average design flow, was maintained during most of September. Most data were obtained from composite sample analysis.

To determine treatment efficiencies of the various plant units, chemical oxygen demand analyses were relied upon to a great extent (a BOD incubator was not yet available). The averages of total COD removed from the influent sewage at various stages of treatment is presented in Figure 14. It will be noted that removal percentages were similar for both rates of flow. Average removal through the plant was 70 per cent at 2.5 mgd and 72 per cent at 1.7 mgd. Average influent COD was 740 ppm and average effluent was 210 ppm at 1.6 mgd; it was 660 and 200 ppm at the 2.5 mgd flow.

Based on COD concentrations entering the various treatment units, values for average per cent COD removed from that applied were calculated and are shown in Table 3.

Later studies were to show that five-day, 20° C BOD was roughly equivalent to 35 per cent of COD. With this approximation, the BOD load applied per acre foot on the filters was estimated to be 2300 pounds per day at 2.5 mgd and 1700 pounds per day at 1.7 mgd. At these flow rates, then, the observed BOD load applied per acre foot was somewhere between

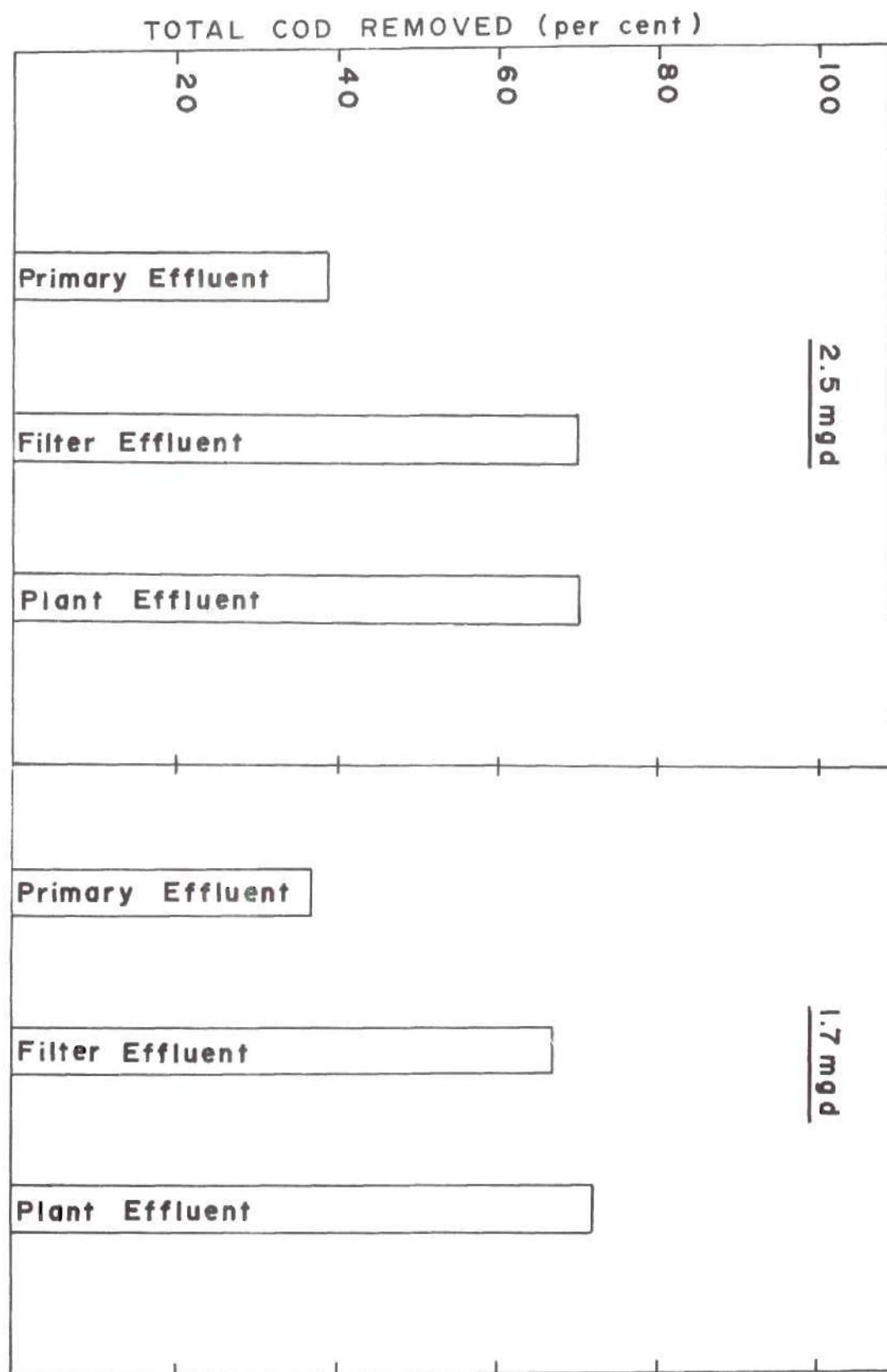


Figure 14. COD Removal--Phase II.

Table 3. Per Cent COD Removed from Applied Load

Plant Unit	2.5 mgd	1.7 mgd
Primary sedimentation	39	37
Standard rate filtration	41	46
Final sedimentation	0	20

the accepted range of 2000 to 5000 pounds per day for high rate operation and 300 to 600 pounds per day for standard rate filtration. Perhaps the poor removal efficiencies listed in Table 3 were caused by overloading and not by surfactant effect.

Other quality characteristics measured during Phase II included anionic surfactant, resistance, pH, temperature, and suspended solids. Average influent and effluent values are shown in Figure 15. Surfactants were consistently measured in the 22 to 24 ppm range at the plant inlet and from 13 to 15 ppm at the outfall. Reduction in surfactants, then, averaged 40 per cent; almost all of which was found to be removed in the trickling filters.

As a measure of plant reduction of dissolved solids, resistance readings showed an average plant influent to effluent increase of 180 ohms (43 per cent increase). Influent readings ranged from 305 to 560 ohms and effluent from 460 to 720 ohms. Because of the wide range of resistance values, the averages in Figure 15 are considered only approximations.

Indicative of the relative strength of the raw sewage was the suspended solids concentration. The average value of 155 ppm shown in Figure 15 was considered in the weak to medium class. Settleable solids which were usually measured at four to six milliliters also were indicative of a sewage of medium strength. The common gray, turbid appearance of normal domestic sewage was rarely evidenced during the study. Instead, the influent sewage was generally colored and transparent enough to distinguish individual waste particles while standing in a 1000-ml Imhoff cone.

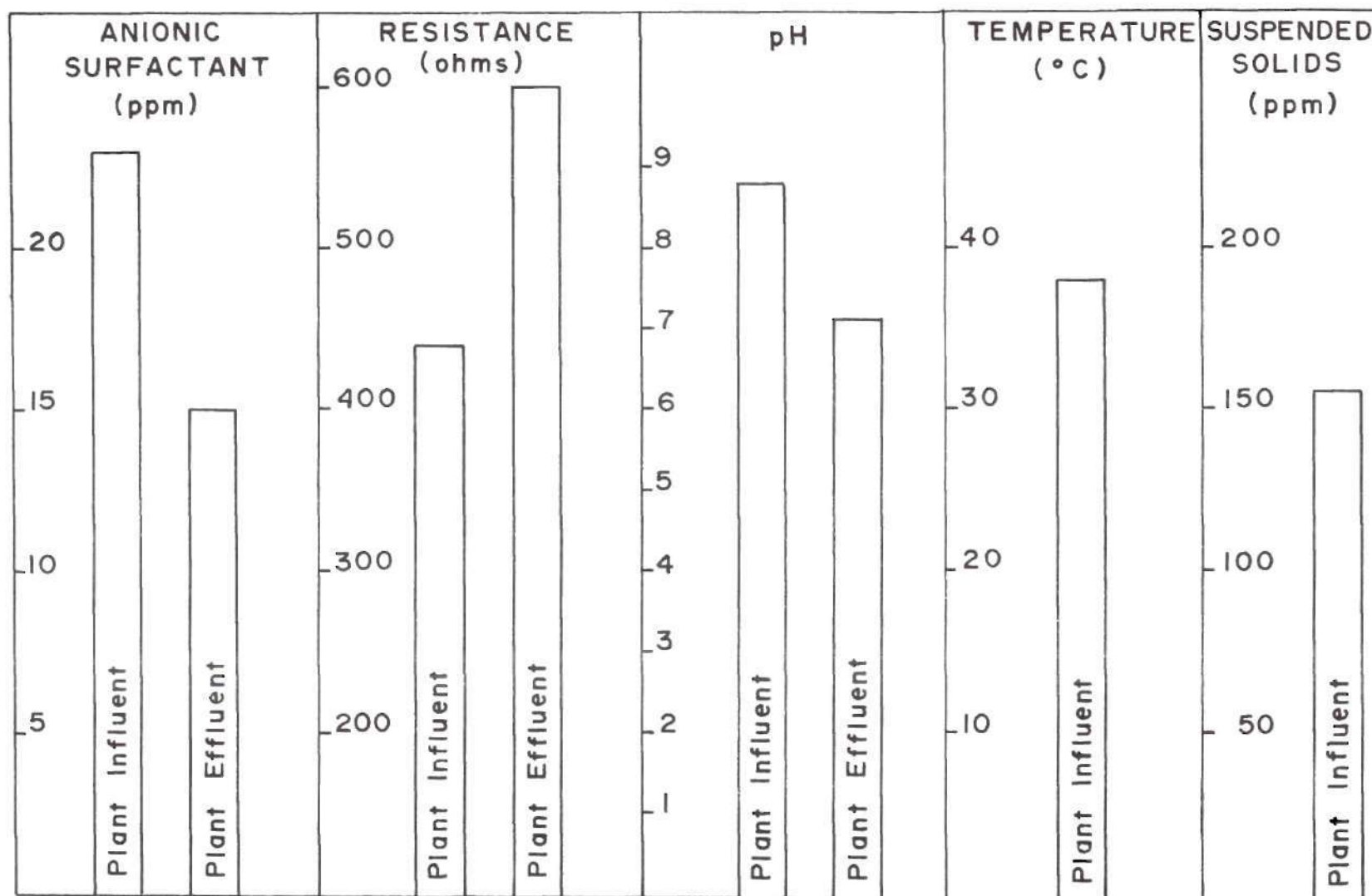


Figure 15. Average Influent and Effluent Quality--Phase II.

At the same time that laboratory studies were being made, visual observations of plant conditions were continued. As in Phase I studies, foaming was never a serious problem. Gas production in the digester did decrease by an appreciable amount on August 20, 21, and 22. The cause was believed to be from a particularly acidic (pH 5.8) volume of raw sludge pumped to the digester. Another possible and related cause could have been a large concentration of high sulfide content sludge. Sulfates entering the plant were detected in concentrations as high as 4800 ppm. Aulenbach and Heukelekian's studies (64) showed that sulfide could interfere with digestion processes. Some of the sulfates entering the plant would be reduced to sulfide in raw sludge.

The influent and effluent averages of pH shown in Figure 15 were 8.8 and 7.1 respectively. According to Steel (65), an oxidized effluent will have a pH of about 7.3. The high effluent COD values would indicate that the sewage effluent was not well oxidized.

An analysis of the digested sludge discharged to the drying beds showed a pH of 6.5 and per cent solids 8.3. These values more closely resemble those of well-digested sludge than values reported in the preliminary study phase. Also, the sludge had the physical features of a well-digested sludge, i.e. black color and earthy smell.

Influent temperature averaged 38° C during Phase II. This figure is high and was caused by the large amounts of heated industrial process water in the sewage reaching the waste treatment plant.

Study Results--Phase III

The third and last phase of the Dalton study was made under

different plant and climatic conditions. Alterations were completed on October 21, 1958, which provided for high rate, series operation of the plant's trickling filters. Consulting engineers for the City of Dalton (Wiedeman and Singleton Engineering, Atlanta, Georgia) hoped that the changes in treatment processes would result in an improved sewage effluent quality.

Changes in climatic conditions for the last study phase were seasonal and were partially responsible for changes in trickling filter slime growth evinced by an excessive amount of sloughing.

Five-day, 20° C BOD was the quality characteristic most depended on for evaluation of treatment efficiencies. Results of total BOD removed at different stages of treatment together with per cent of applied BOD removed by the various units are illustrated in Figure 16. The bar graphs are indicative of average BOD removal at all flow rates used for Phase III. In regard to the range of test flows, Phase III studies of the plant were conducted at the 1.5 mgd design flow and at the peak capacity of recirculation pumps, approximately 2.0 mgd. No appreciable differences in plant BOD removal efficiencies at either flow rate were detected.

There were, however, widely divergent results for primary settling efficiencies. Because of this, the bar graphs in Figure 16 illustrate maximum and minimum values for the primary sedimentation unit. Average plant influent concentration was 350 ppm of five-day, 20° C BOD; a strong sewage. Primary treatment removed from 1 per cent to 23 per cent of the applied BOD load, far less than the normally expected 30 to 35 per cent removal rate for primary sedimentation. Because of poor BOD removal from

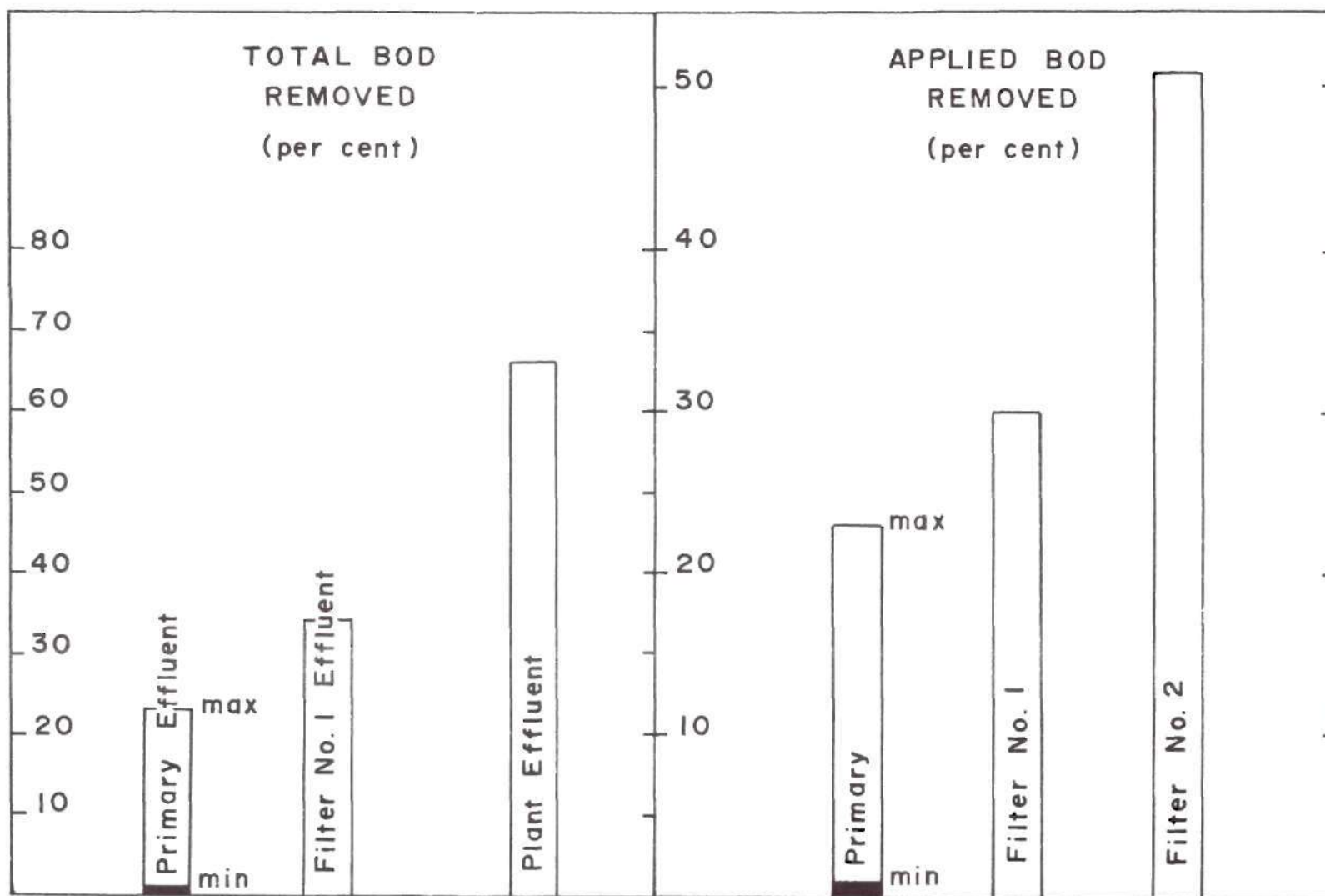


Figure 16. BOD Removal--Phase III.

initial settling, the applied BOD load on Filter No. 1 was high.

The approximate average BOD load placed on the first filter was 2900 lb/acre-ft/day, a high rate loading. Since only 30 per cent of the applied BOD was removed by Filter No. 1, and since little removal was effected in the intermediate settling basin, the BOD load placed on Filter No. 2 was also high. The load averaged 2300 lb/acre-ft/day, also in the high rate filtration range. Removal efficiency of the second filter improved to 51 per cent, but this was still less than normal reported average removal of 65 to 80 per cent.

Phase III data showed that total BOD removal through the plant was 66 per cent. Correlation studies were performed to determine the BOD-COD ratio (Figure 17). With an estimated ratio of 0.35, total BOD removal determined for Phase II conditions was roughly equivalent to removal for Phase III high rate, series operation. In neither case did treatment efficiencies approach expected 85 to 95 per cent BOD removal for standard or high rate filtration plants.

Dissolved oxygen (DO) concentrations in filter effluents further indicated the inefficient operation of the filter units. Well-oxidized filter effluent usually has a DO concentration of 50 per cent of saturation. The DO study results for Filter No. 1 effluent averaged 1.9 ppm (30 per cent of saturation) and for Filter No. 2, 2.7 ppm (35 per cent of saturation). From these DO analyses, interferences with treatment processes were implied.

As analyses indicated, anionic surfactant concentrations in the sewage influent remained in the 24 ppm range and was approximately 14 ppm as discharged. Limited data obtained on other parameters showed

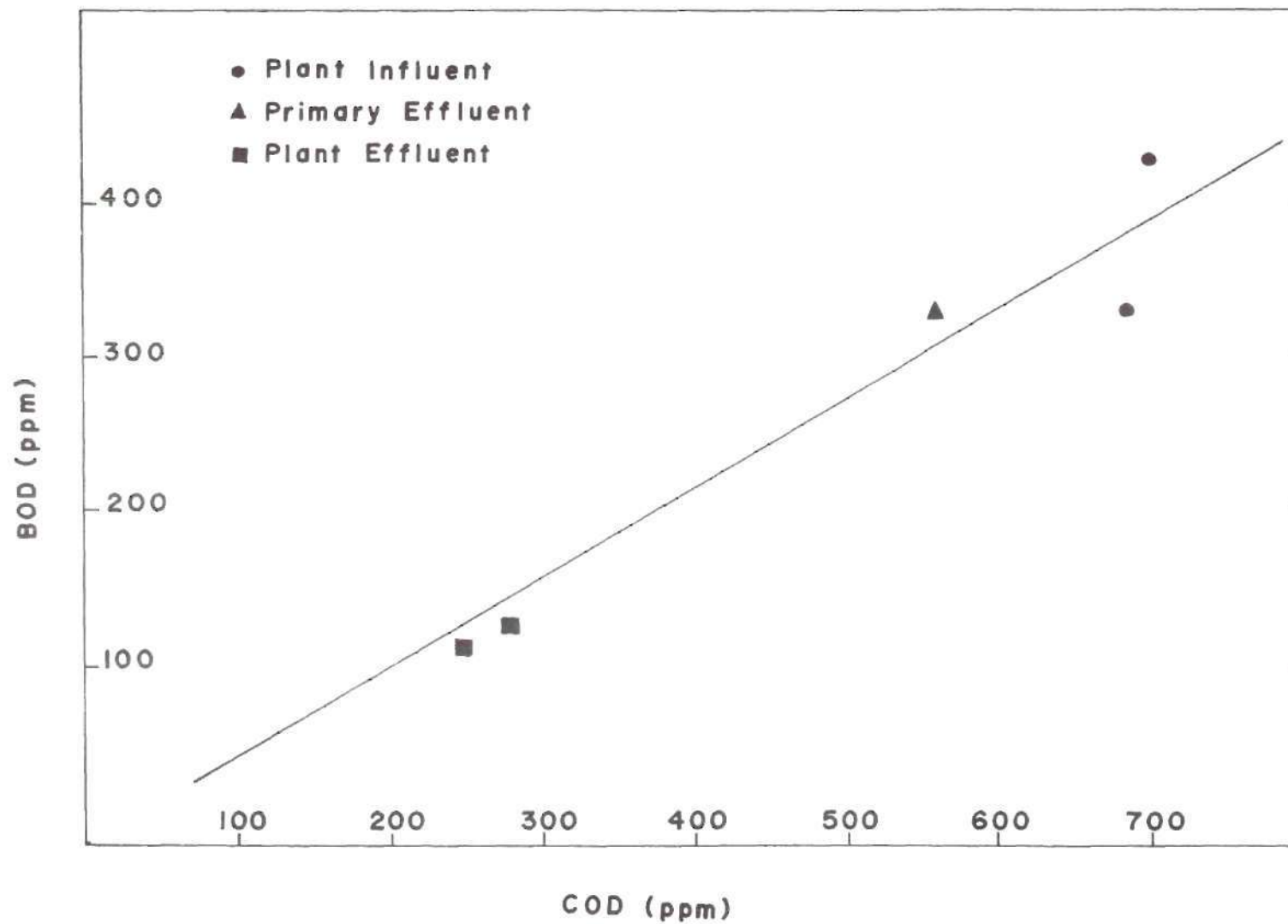


Figure 17. BOD Versus COD.

that chloride was present in concentrations exceeding 1000 ppm (12 per cent removal through the plant). The data also indicated that settleable solids removal in the primary settling basin was 86 per cent with an average influent content of 6.5 ml. COD removal during the final study phase was 62 per cent, less than the 70 to 72 per cent obtained during Phase II studies.

Sludge digestion proceeded satisfactorily during the October and November Phase III period with one exception. On November 6, gas production decreased substantially when raw sewage was pumped into the digester by accident.

Causes of Poor Treatment at the Dalton Plant

The stated purpose of the Dalton investigation was to evaluate the effects of high (up to 36 ppm) surfactant concentrations on the waste treatment plant. Analytical data obtained during each of the three study phases definitely indicated that BOD and COD removal efficiencies were less than expected for a trickling filter-type plant. In addition, the primary sedimentation basin did not operate properly at times, and the digester occasionally failed to produce enough sludge gas to fuel the heat exchanger. Were all these difficulties due to the presence of surfactants?

Sawyer and Lynch's (41) study reported in 1954 concluded that ABS type syndets reduced oxygen transfer rates during sewage aeration. Barden and Isaac's (47) research further indicated that surfactants suppressed oxygen transfer rates in trickling filters, especially for overloaded plants, and especially when syndet concentrations exceeded 20 ppm.

Based on these studies, it might be reasonably expected that reported treatment difficulties at Dalton were caused by surfactants.

Another possibility was that the industrial waste portion of Dalton sewage, which included substances such as sulfates and chlorides together with surfactants, could produce detrimental synergistic effects. A 1937 basic research study (1) on synthetic detergency purported that the presence of sodium and calcium salts had the effect of lowering surface tension beyond that obtained in a pure detergent solution. This conclusion would tend to explain the difficulties experienced with oxygen transfer in the trickling filters. Certainly sodium chloride was present in substantial amounts (over 1000 ppm chloride reported).

Viewing the poor treatment efficiency problem from another standpoint, one might say that design, construction, and operation deficiencies together with overloading of the plant was the cause. The following deficiencies were observed during the investigation:

(1) There was no grit chamber. While separate sewer systems do not always indicate the need for this unit, the Dalton plant did require one because of large amounts of grit from poultry processing wastes.

(2) The comminutors, which were inoperative due to corroded parts, had not been replaced. Large textile waste objects frequently passed through the bar screen and into the wet well.

(3) Thick scum and grit deposits built up rapidly in the wet well. Frequent cleaning with a fire hose was necessary. At times, the entire plant had to be shut down to clean the wet well. Much of the grit from these cleanings eventually reached the digester.

(4) Operation of the wet well pumps was such that shock loads were transmitted to the primary sedimentation unit. Attempts to stabilize influent flows met with little success.

(5) Based on dye studies of detention time, it was determined that short-circuiting in the primary settling tanks occurred frequently. Detention periods as short as 30 minutes were observed. The cause of short-circuiting was not definitely established, but it was believed to be a combination of thermal stratification and surges from pumping.

(6) Location of the Parshall flume following the primary basin subjected it to surges caused by the wet well pumping routine. Consequently, maintenance of desired flows could only be obtained through observation of differences in total flow over a long period of time.

(7) The dosing tank siphons never operated effectively during the study period. Because of corroded parts, they served only as open valves.

(8) The size and type of filter stone was improperly selected. Incorrect gradation of rock during filter bed construction resulted in a homogeneous mixture of stone as large as six inches in diameter and as small as one inch (Figure 18). The result was insufficient void space for proper aeration.

The type of stone used was probably questionable. A limestone was used which provided less wetted surface area than is normally considered desirable. As shown in Figures 19 and 20, slime growth on the limestone surface was poor compared to luxuriant growth on a small section of slag placed in one filter. More effective treatment would have resulted if a 1.5 to 3-inch slag had been used instead of poorly



Figure 18. Comparative Sizes of Trickling Filter Stone.

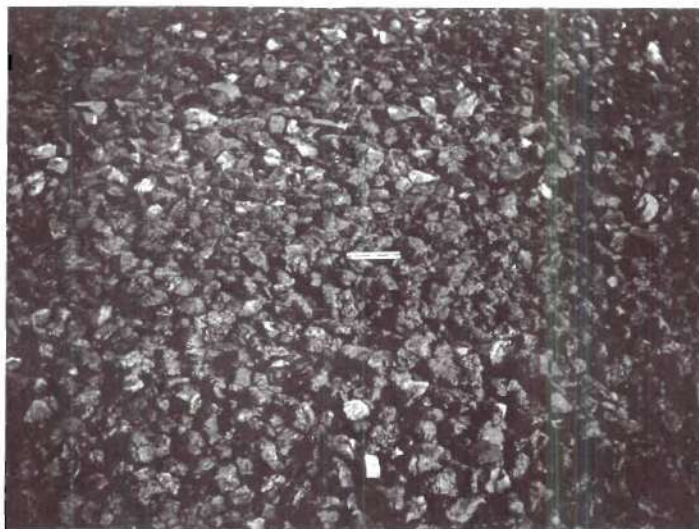


Figure 19. Slime on Slag Stone Area (Six-inch Rule).



Figure 20. Slime on Slag Stone Area (Six-inch Rule).

graded limestone.

(9) Frequent breakdown of various treatment units was the rule rather than the exception. During the study, switches in the wet well frequently clogged with scum; bearings for the trickling filter distributor arms failed; time switches for sludge pumps corroded to the point of unreliability, mechanical sludge collectors failed (Figure 21), and sludge pumps in the final settling basin had to be replaced. Some of the breakdowns were caused, of course, by normal deterioration, but associated repairs required as much as one week to complete. Portions of the plant were rendered inoperative during repair periods.

(10) No routine laboratory control of the plant was practiced.

Many of the above plant deficiencies could detrimentally affect waste treatment processes.

Yet another possible cause of poor treatment at the Dalton plant was the effect of high temperature sewage on the trickling filters. In 1962, Minch, Egan, and Sandlin (66) reported on operation of plastic filter media. Their studies indicated erratic and relatively poorer filter operation in the 32° C to 45° C temperature range, the approximate same range as for Dalton's sewage.

One sees, then, that Dalton's waste treatment plant problems could be caused by many of the above-mentioned factors. Surfactants may well be a deleterious agent affecting plant operations. The investigation results reported in this paper, however, do not definitely indicate this. Additional data should be collected when the sewage has a relatively low anionic surfactant concentration. The results of such a study could be compared to data reported here to determine possible improvements

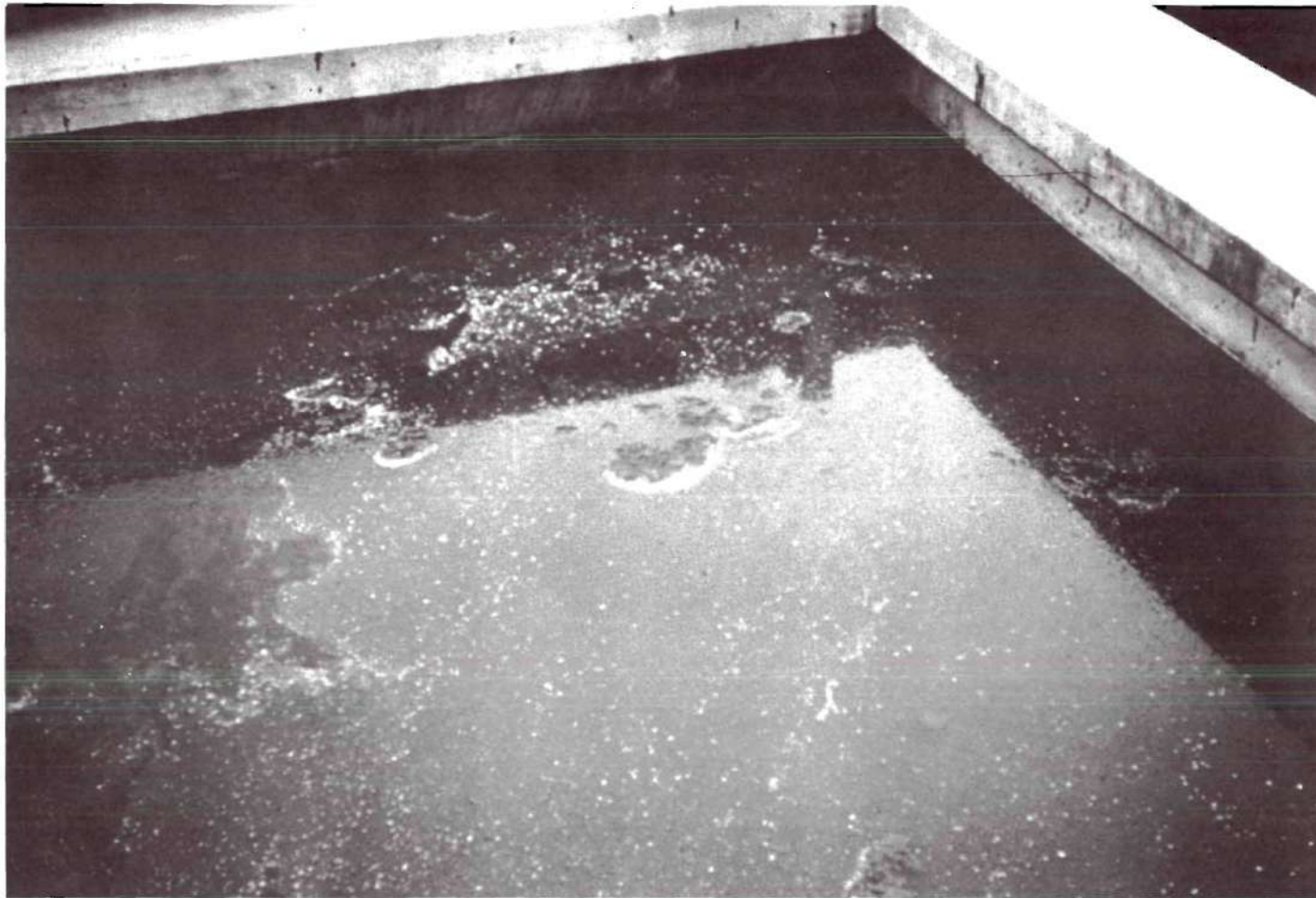


Figure 21. Septic Condition in Final Settling Basin.

in waste removal efficiencies.

Based on results of the July through November 1958 study, the writer feels that inefficient waste treatment operation at Dalton, Georgia, was caused by a combination of the possible causative factors discussed above. Deficiencies in plant design, construction, and operation were believed to be the primary suspects.

CHAPTER VII

CONCLUSIONS

Literature research and the July through November 1958 investigation at the Dalton, Georgia, sewage treatment plant indicated that:

(1) Synthetic detergents have been detrimental to sewage treatment processes in this country and elsewhere.

(2) Synthetic detergents containing an alkyl benzene sulfonate (ABS) type of surfactant are the most harmful.

(3) Sewage entered the Dalton plant from domestic and industrial (primarily tufted textile industries) sources at average flows of 1.0 and 4.0 million gallons per day (mgd), respectively. The plant was designed for an average flow of 1.5 mgd.

(4) Dalton sewage contained anionic surfactants in concentrations as high as 36 parts per million (ppm), but which consistently ranged between 22 and 25 ppm.

(5) Dalton sewage contained large amounts of sulfate and chloride, sometimes exceeding 1000 ppm, as well as occasional free chlorine and a variety of organic and inorganic textile dyeing wastes.

(6) Average COD concentration of sewage entering the plant was 700 ppm.

(7) Average BOD concentration of sewage entering the plant was 350 ppm.

(8) COD removal effected by the plant at a 2.5 mgd rate

averaged 70 per cent, and at the average design flow rate of 1.5 mgd, it averaged 72 per cent.

(9) BOD removal effected by the plant at flow rates of from 1.5 to 2.5 mgd averaged only 66 per cent, with little variation at the different test flows.

(10) BOD removal by primary sedimentation ranged from 1 per cent to 23 per cent and short-circuiting was evident.

(11) Trickling filters removed from 30 to 50 per cent of applied BOD during parallel and series operation. Loadings ranging from 1500 to 2500 lb BOD/acre-ft/day indicated overloading.

(12) Sludge gas from the digester was occasionally produced in quantities insufficient to fuel the heat exchanger.

(13) Studies of plant design, construction, and operation features revealed numerous deficiencies.

(14) Factors such as synergistic effects of surfactants and sodium salts, and high influent sewage temperature (36°C to 41°C) may detrimentally affect trickling filter operation.

(15) Overloading of a waste treatment plant found to have design, construction, and operation deficiencies was believed to be the major cause of Dalton's waste treatment problems, although the highly complex nature of Dalton's sewage could have further aggravated treatment deficiencies.

(16) The effect of synthetic detergents was not thoroughly defined but was believed to aggravate treatment problems only to a minor extent. Removal of anionic surfactant by the plant averaged 40 per cent, and most of this was effected in the trickling filters.

CHAPTER VIII

RECOMMENDATIONS

Continuing studies of the Dalton, Georgia, sewage treatment plant should be made. Such future studies should include greater emphasis on the quality characteristics of BOD and DO than was possible in the July through November 1958 study. Photometric equipment should be utilized for anionic surfactant analyses.

Although physical deficiencies in plant design, construction, and operation were considered chiefly responsible for poor waste removal efficiencies, the effect of surfactant content might be more thoroughly investigated. If possible, sustained periods of study, preferably one week or longer, should be conducted during minimum textile industry operation. This would provide for observation of plant operation during periods of low surfactant concentration. Comparisons might then be made with results reported in this thesis.

APPENDIX A

STUDY DATA TABULATION

1

Table 4. Dalton, Georgia, Sewage Treatment Plant Study, July--November, 1958

Date	Sampling Point	Type Sample	Flow Rate (mgd)	Anionic Surfactant (ppm)	pH	Resistance (ohms)	COD (ppm)	Temperature (°C)	Chlorides (ppm)	Remarks
PHASE I										
7/22/58	Plant Influent	Grab	2.5	20						With shaking
"	"	"	"	"						Without shaking
7/29/58	"	" (9 a.m.)		24	8.0	480*		40		*At 31° C
"	"	Distilled water				250,000**				**At 31° C
"	Plant Influent	Grab (2 p.m.)			7.5	330		39		Supernatant pH-7.1 Sludge pH-6.6
7/30/58	"	" (10 a.m.)		23	6.8	280		37		Foamy, blue-green color
8/5/58	"	" (5 p.m.)		24						Foamy
8/6/58	"	" (8 a.m.)		25	6.7	800		36		Tan color, little foam
"	"	" (9 a.m.)		22	8.5	430		39		" " " "
"	"	" (10 a.m.)		36	7.6	515		39		Green color, foamy
"	"	" (11 a.m.)		24	9.7	360		41		Pink color, some foam
"	"	" (12 p.m.)			7.0	320		40		Green color, foamy
"	Plant Effluent	" (1 p.m.)		15	6.9	515		35		Gray color
"	Plant Influent	" (3 p.m.)			7.3	520		38		Pink color, little foam
"	Plant Effluent	" "		15	7.1	480		35		Gray color
8/7/58	Plant Influent	" (6 a.m.)		22	10.4	570		35		Gray color, little foam
8/12/58	"	" (4 p.m.)		26	7.1	230		42		Blue color
8/13/58	"	" (10 a.m.)			8.8	525		40		Pink color, Imhoff cone-8 ml
"	Plant Effluent	" (11 a.m.)	2.4	8	7.9	580	217	34	1120	Influent, Imhoff cone-4 ml
"	Plant Influent	Composite	2.4	23						7-hr composite, 10 p.m.-5 a.m.
"	Digester	Sludge			7.4					
										per cent solids - 6.5
										per cent solids volatile - 34
										per cent solids fixed - 66

Table 4. (Continued)

Date	Sampling Point	Type Sample	Flow Rate (mgd)	Anionic Surfactant (ppm)	pH	Resistance (ohms)	COD (ppm)	Temperature (°C)	Suspended Solids (ppm)	Chlorides (ppm)	Sulfate (ppm)	Remarks
PHASE II												
8/14/58	Plant Influent	Grab (1 p.m.)										Imhoff cone-5.5 ml
8/15/58	" "	Composite	2.4	22	8.3	390	670			1210		pH of sludge in final basin-5.8
"	Filter Effluent	"	"	14	7.0	620	180			1200		
"	Plant Effluent	"	"	13	7.0	620	180			1080		
8/17/58	Plant Influent	Grab (1 p.m.)		4								Sunday sample
8/20/58	Plant Influent	Composite	2.5	22	9.9	305	720	37	152	1320		Imhoff cones-6, 8.5 & 5 ml
"	Primary Effluent	"	"	20	6.8	470	425	37		1290		Digester gas production nil, raw sludge pH-5.8
"	Filter Effluent	"	"		7.4	470	248			1295		
8/21/58	Plant Influent	"	2.4		7.5	530	670		160	1230		Gas production still off.
"	Primary Effluent	"	"		7.4	680	425			1135		Plant shut down at 11 a.m. to clean wet well.
"	Plant Effluent	"	"		7.0	700	220			1090		
9/8/58	Plant Influent	Grab (4 p.m.)			7.1	465		39				Imhoff cone-5 ml
9/9/58	" "	" (7 a.m.)		24	9.2	400	680	39		1170		Gray color
"	" "	Composite	1.7	23	9.1	330	815	36	150	1420		Imhoff cone-24 ml, green
"	Primary Effluent	"	"	23	8.0	410	610	36		1320		
"	Filter Effluent	"	"		7.1	440	330	35		1300		
"	Plant Effluent	"	"	15	7.1	460	300	35		1310		
9/10/58	Plant Influent	"	1.6	24	8.0	420	710	38		1480		Light brown color
"	Primary Effluent	"	"		6.6	560	370	38		1200		
"	Filter Effluent	"	"		7.3	640	200	34		1060		
"	Plant Effluent	"	"	14	7.3	720	140	31		1040		

Table 4. (Continued)

Date	Sampling Point	Type Sample	Flow Rate (mgd)	Anionic Surfactant (ppm)	pH	Resistance (ohms)	COD (ppm)	Temperature (°C)	Suspended Solids (ppm)	Chlorides (ppm)	Sulfate (ppm)	Remarks
PHASE II (cont'd)												
9/11/58												Plant shut down to repair broken sludge collector at final basin.
9/16/58												Plant restarted.
9/17/58	Plant Influent	Grab										Imhoff cone- 2.5 ml Limited slime on stones due to shutdown.
9/24/58	Plant Influent	Composite	2.3		9.7	375	750			1200		Imhoff cone-4.0 ml
"	Primary Effluent	"	"		7.1	520						Pink color
"	Plant Effluent	"	"		6.8	600	220			1020		" "
9/25/58	Plant Influent	Grab									144	
"	" "	"									1545	
"	Digester	Sludge			6.5							Black color, earthy smell
					per cent solids - 8.3							
					per cent solids volatile - 38							
					per cent solids fixed - 62							
"	Plant Influent	Grab			8.1	310		40			4800	Green color
9/26/58	Plant Influent	Grab (9 a.m.)			9.4	800					390	Brown color, chlorine odor
"	Filter Effluent	" (10 a.m.)				570		34			100	Gray color
10/1/58	Plant Influent	Composite	2.6		9.0	560	550			1250	< 100	Gray and red mixture, rain
"	Primary Effluent	"	"		7.2	590						
"	Plant Effluent	"	"		7.0	630	190			1200		
10/2/58	Plant Influent	"	1.7		9.0	420	680			1410	100	Light rain, red and green
"	Primary Effluent	"	"		6.3	550					100	Oil on surface
"	Plant Effluent	"	"		7.0	620	180			1190	50	
10/2--21/58												Plant shut down to install recirculation pumps.

Table 4. (Continued)

Date	Sampling Point	Type Sample	Flow Rate (mgd)	Anionic Surface-tant (ppm)	pH	Resist-ance (ohms)	COD (ppm)	5-Day BOD (ppm)	Tempera-ture (°C)	Chlorides (ppm)	Remarks
PHASE III											
10/22/58	Plant Influent	Composite	1.9	25		370	820			1230	Difficult to maintain 2 mgd recirculation. Effluent appears clearer and has more foam. Sloughing from second filter.
"	Filter No. 2 Effluent	"	"				360			1100	
"	Plant Effluent	"	"			500	305			1190	
10/23/58											Less foam and sloughing. Difficulty in recirculation
10/29/58	Filter No. 2 Effluent	Grab					270*			1310	*Unfiltered sample
"	Filter No. 2 Effluent	"					160**			1300	**Filtered with No. 1 paper
10/30/58	Plant Influent	" (9 a.m.)	1.9					390			
"	Plant Effluent	" (4 p.m.)	"					115			
10/31/58	Plant Influent	Composite	1.9					277			
"	Primary Effluent	"	"								
"	Intermediate Effl.	"	"					195			
"	Plant Effluent	"	"					125			
11/4/58											Sludge rising in final; filters flooded; filter No. 1 breakdown.
11/6/58											Gas production off due to failure of pumps to shut off at primary.
11/7/58	Plant Influent	Grab (2 p.m.)	1.9					335			
"	Primary Effluent	"	"					260			
"	Filter No. 1 Effluent	"	"					226			DO of filter effluent-3 ppm
"	Plant Effluent	" (6 p.m.)	"					216			

Table 4. (Continued)

Date	Sampling Point	Type Sample	Flow Rate (mgd)	Anionic Surface-tant (ppm)	pH	Resist-ance (ohms)	COD (ppm)	5-Day BOD (ppm)	Tempera-ture (°C)	Chlorides	Remarks
PHASE III (cont'd)											
11/9/58	Plant Influent	Composite	1.5					290			Sunday sample
"	Plant Effluent	"	"					95			
11/10/58											Chlorinated No. 2 filter with 300 lb ETH; slime removed from top of stone.
11/11/58											Sludge removal device in a final tank failed.
11/12/58											Sludge rising in other final tank; considerable sloughing from filter No. 2; DO from Filter No. 2-2 ppm.
11/13/58	Plant Influent	Composite	1.8		9.1	590	685	330	35	1270	
"	Primary Effluent	"	"		7.4	610		320	35		
"	Intermediate Effl.	"	"		7.4	650		245	32		
"	Plant Effluent	"	"		8.2	650	280	125	28	1150	
11/14/58											Plant shut down to repair final tank. Restarted 11/18/58.
11/19/58	Plant Influent	Composite	1.6	24		560	700	430		1510	Light rain overnight
"	Primary Effluent	"	"			530	560	330		1470	
"	Intermediate Effl.	"	"			580		220			
"	Plant Effluent	"	"	14		610	250	110		1300	
11/20/58	Plant Influent	"	1.5			550		380			Imhoff cone-6.5 ml
"	Primary Effluent	"	"					375			" " -0.9 ml
"	Intermediate Effl.	"	"					260			
"	Plant Effluent	"	"					120			
11/21/58	Filter No. 2 Effluent	Grab									Imhoff cone-8 ml
11/25 & 30/58	Special DO Studies: On 11/25/58 at 8:30 a.m., Filter No. 1 was 1.8 ppm and Filter No. 2 was 3.5 ppm; at 11 a.m., Filter No. 1 was 1.0 ppm and Filter No. 2 was 2.6 ppm; at 3 p.m., Filter No. 2 was 2.5 ppm. On 11/30/58, Filter No. 2 was 6.6 ppm.										

BIBLIOGRAPHY

LITERATURE CITED

- (1) J. Powney and C. C. Addison, "The Properties of Detergent Solutions. II. The Surface and Interfacial Tensions of Aqueous Solutions of Alkyl Sodium Sulfates," Transactions Faraday Society, 33, 1243 (1937).
- (2) Anonymous, "Detergent Market Sets All Time Record," Soap and Chemical Specialties, 38, 3, 159 (March 1962).
- (3) J. M. Cohen, "Syndets in Water Supplies," Soap and Chemical Specialties, 35, 9, 53 (1959).
- (4) R. E. McKinney and J. M. Symons, "Bacterial Degradation of ABS. I. Fundamental Biochemistry," Sewage and Industrial Wastes, 31, 549 (1959).
- (5) S. Lenher, "Uses of Wetting Agents," Chemical Industry, 60, 27, 497 (1941).
- (6) Anonymous, "What Caused the Suds in the Sewage Treatment Plant," American City, 42, 12, 99 (1947).
- (7) A. Sciver, "Synthetic Detergents and Sewage Processing. Part II. Sedimentation of Sewage," Institute of Sewage Purification, Journal and Proceedings, Part 3, 354 (1949).
- (8) P. N. Degens et al., "Production of Methane from Sewage Sludge," Inst. Sewage Purif., J. and Proc., Part 3, 359-65 (1949).
- (9) H. H. Evans and P. A. Winsor, "Synthetic Detergents and Sewage Processing. Part IV. Processing of Sewage Containing Wool Scouring Wastes," Inst. Sewage Purif., J. and Proc., Part 3, 365 (1949).
- (10) W. Rudolfs, R. Manganelli, and I. Gellman, "Effect of Certain Detergents on Sewage Treatment," Sewage Works Journal, 21, 4, 605 (1949).
- (11) Central States Sewage Works Assoc.--Operators Forum, "Frothing of Aerators," Sewage Industr. Wastes, 22, 9, 1238 (1950).
- (12) P. N. Degens et al., "Synthetic Detergents and Water Processing. V. Effect of Synthetic Detergents on Certain Water Fauna," Inst. Sewage Purif., J. and Proc., Part I, 63 (1950).
- (13) H. H. Goldthorpe and J. Nixon, "Further Experiments with Synthetic Detergents at Huddersfield, Particularly with Respect to Their Action on Percolating Beds," Journal of the Royal Sanitary Institute, 70, 116 (1950).

- (14) J. Hurley, "The Influence of Synthetic Detergents on Sewage Treatment," Inst. Sewage Purif., J. and Proc., Part 3, 249 (1950).
- (15) W. Rudolfs and R. M. Manganelli, "Sewage Treatment Problems in Relation to Detergents," Soap and Sanitary Chemistry, 27, 79 (1951).
- (16) C. N. Sawyer, "Syndets in Relation to Biological Problems in Lakes," Soap and Sanit. Chem., 27, 79 (1951).
- (17) W. Rudolfs and E. S. Crosby, "Effect of Detergents on Slime Growths in Sewers," Soap and Sanit. Chem., 27, 79 (1951).
- (18) 1950 Operator's Forum, "Effect of Detergents on Sewage Treatment Plants," Sewage Industr. Wastes, 23, 5, 675 (1951).
- (19) S. L. Allison, "How Aeration Tank Foaming Troubles Were Conquered," Public Works, N. Y., 83, 3, 87 (1952).
- (20) W. C. Anderson, "Tips and Quips," Sewage Industr. Wastes, 24, 5, 680 (1952).
- (21) W. N. Wells and C. H. Scherer, "Froth Formation and Synthetic Detergents," Sewage Industr. Wastes, 24, 5, 671 (1952).
- (22) P. N. Degens, "Review of Experience with Froth Formation in Sewage Treatment Plants," Sewage Industr. Wastes, 26, 12, 1494 (1954).
- (23) H. E. Berg, "Operating Experiences with Detergents at Washington, D.C. - Discussion," Sewage Industr. Wastes, 25, 277 (1953).
- (24) R. H. Bogan and C. N. Sawyer, "Biochemical Degradation of Synthetic Detergents. III. Relationships Between Biological Degradation and Froth Persistence," Sewage Industr. Wastes, 28, 5, 637 (1956).
- (25) W. R. Gowdy, "Action of Detergents in Sewage Treatment - A Study by Industry," Sewage Industr. Wastes, 25, 3, 255 (1953).
- (26) L. A. Munro, M. Yatabe, and W. J. Abrams, "Pilot-Plant Studies of Frothing in Sewage Treatment Plants," Sewage Industr. Wastes, 28, 10, 1232 (1956).
- (27) L. A. Munro and M. Yatabe, "Frothing of Synthetic Sewages," Sewage Industr. Wastes, 29, 8, 883 (1957).
- (28) L. B. Polkowski, G. A. Rohlich, and J. R. Simpson, "Evaluation of Frothing in Sewage Treatment Plants," Sewage Industr. Wastes, 31, 9, 1004 (1959).
- (29) R. Eliassen, "Basic Principles of Detergency," Water and Sewage Works, 99, 5, 208-9 (May 1952).

- (30) A. L. Meader and B. A. Hies, "Adsorption in the Detergent Process," Industrial and Engineering Chemistry, 44, 7, 1636 (1952).
- (31) R. Manganelli, "Detergents and Sewage Treatment," Sewage Industr. Wastes, 24, 9, 1057 (1952).
- (32) R. W. Fuhrman and J. E. Rice, "Operating Experiences with Detergents at Washington, D.C.," Sewage Industr. Wastes, 25, 3, 277 (1953).
- (33) C. Lumb, "The Effects of Synthetic Detergents on Sewage Purification; A Summary of Current Knowledge," Water and Sanitary Engineering, 3, 7, 53 (1952).
- (34) C. Lumb, "Experiments on the Effects of Certain Synthetic Detergents on Biological Oxidation of Sewage," Inst. Sewage Purif., J. and Proc., Part 4, 269 (1953).
- (35) P. C. G. Isaac, "Synthetic Detergents: Their Effect on Sewage Treatment and Water Supply," Wat. Sanit. Engrng., 3, 413 (1953).
- (36) W. Rudolfs, "Detergent Compounds - Their Composition and Behavior - Discussion," Sewage Industr. Wastes, 25, 3, 245 (1953).
- (37) W. R. Gowdy, "Chemical Structure and the Action of Synthetic Detergents," Sewage Industr. Wastes, 25, 1, 15 (1953).
- (38) L. Flett and L. Hoyt, "Detergent Compounds - Their Composition and Behavior," Sewage Industr. Wastes, 25, 3, 245 (1953).
- (39) F. H. Lehberg, "Synthetic Detergents and Their Effect on Sewage-Treatment Processes," Municipal Utilities, 91, 11, 54 (1953).
- (40) R. H. Bogan and C. N. Sawyer, "Biochemical Degradation of Synthetic Detergents. I. Preliminary Studies," Sewage Industr. Wastes, 26, 9, 1069 (1954).
- (41) W. O. Lynch and C. N. Sawyer, "Physical Behavior of Synthetic Detergents. I. Preliminary Studies on Frothing and Oxygen Transfer," Sewage Industr. Wastes, 26, 10, 1193 (1954).
- (42) R. H. Bogan and C. N. Sawyer, "Biochemical Degradation of Synthetic Detergents. II. Relation Between Chemical Structure and Biochemical Oxidation," Sewage Industr. Wastes, 27, 8, 917 (1955).
- (43) C. Hammerton, "Observations on the Decay of Synthetic Anionic Detergents in Natural Waters," Journal of Applied Chemistry, 5, 517 (1955).
- (44) W. T. Lockett, "Synthetic Detergents in Relation to the Purification of Sewage," Inst. Sewage Purif., J. and Proc., Part 3, 225 (1956).

- (45) R. M. Manganelli, "Effects of Synthetic Detergents on Activated Sludge," Wat. & Sewage Wks., 103, 9, 424 (1956).
- (46) R. D. Raybould and L. H. Thompson, "Some Large-Scale Investigations on the Influence of Alkyl Benzene Sulphonate Detergents on Sewage Purification," Surveyor, (London), 115, 3332, 41 (1956).
- (47) L. Barden and P. C. G. Isaac, "Effect of Synthetic Detergents on the Biological Stabilization of Sewage," Proceedings, Institute of Civil Engineers, (London), 6, 371 (1957).
- (48) R. E. McKinney, "Syndets and Waste Disposal," Sewage Industr. Wastes, 29, 6, 654 (1957).
- (49) H. Mann and D. W. M. Herbert, "Some Observations of the Effect of Synthetic Detergents on the Treatment of Sewage," Wat. Sanit. Engrng., 6, 206 (1957).
- (50) F. J. Coughlin, "Detergents are Degraded in Sewage Treatment Plants," Wastes Engineering, 30, 36, 42 (1959).
- (51) P. H. McGauhey and S. A. Klein, "Removal of ABS by Sewage Treatment," Sewage Industr. Wastes, 31, 8, 877 (1959).
- (52) G. W. Malaney, W. D. Sheets, and J. Ayres, "Effects of Anionic Surface-Active Agents on Waste-Water Treatment Units," Journal of the Water Pollution Control Federation, 32, 11, 1161 (1960).
- (53) P. J. Weaver, "Review of Detergent Research Programme," J. Water Pollut. Control Fed., 32, 3, 288 (1960).
- (54) A. L. Downing and L. F. Scragg, "The Effect of Synthetic Detergents on the Rate of Aeration in Duffused Air Activated Sludge Plants," Water and Waste Treatment Journal, 7, 102 (1958).
- (55) C. N. Sawyer, "Effects of Synthetic Detergents on Sewage Treatment Processes," Sewage Industr. Wastes, 30, 6, 757 (1958).
- (56) J. W. Hernandez and D. E. Bloodgood, "The Effects of ABS on Anaerobic Sludge Digestion," J. Water Pollut. Control Fed., 32, 12, 1261 (1960).
- (57) F. J. Ludzack and M. B. Ettinger, "Chemical Structures Resistant to Aerobic Biochemical Stabilization," J. Water Pollut. Control Fed., 32, 11, 1173 (1960).
- (58) M. Lieber, "Syndet Removal from Drinking Water Using Activated Carbon," Wat. & Sewage Wks., 107, 8, 299 (1960).

- (59) American Public Health Assoc., American Water Works Assoc., Federation of sewage and Industrial Waste Assoc., Standard Methods for the Examination of Water, Sewage, and Industrial Waste, Waverly Press, Inc., Baltimore, Md., Tenth Edition, 1955.
- (60) Wiedeman and Singleton Engineers, "Interim Report on Sewage Treatment Plant Improvements, Dalton, Georgia," 1957.
- (61) S. Longwell and W. D. Maniece, "Determination of Anionic Detergents in Sewage, Sewage Effluents, and River Waters," The Analyst, 80, 167 (1955).
- (62) APHA, AWWA, and WPCF, Standard Methods for the Examination of Water and Wastewater, Eleventh Edition, 1962.
- (63) R. S. Ingols, "Syndets Kill Settling Efficiency," Wastes Engineering, 29, 6 (June 1958).
- (64) D. B. Aulenbach and H. Feukelekian, "Transformation and Effects of Reduced Sulfur Compounds in Sludge Digestion," Sewage Industr. Wastes, 27, 10, 1147 (1955).
- (65) E. W. Steel, Water Supply and Sewerage, McGraw-Hill Book Co., New York, Third Edition, 1953.
- (66) V. A. Minch, J. T. Egan, and M. Sandlin, "Design and Operation of Plastic Filter Media," J. Water Pollut. Control Fed., 34, 5, 459 (1962).